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FORECASTING COMPOSITION AND WEIGHT OF HOUSEHOLD SOLID WASTES USING INPUT-OUTPUT TECHNIQUES

Volume I

by

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Contract No. 68-03-0261

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16. ABSTRACT

An input-output approach is employed to project future production inputs for selected industrial sectors. Extrapolations are made for subsequent household solid waste composition and quantities. Considerable effort is directed at developing a highly detailed analysis of the material flows which define the interdependencies of producing and consuming sectors in the economy. Using the INFORUM model, projections of selected industry sector productivities and subsequent household waste generation were made, taking into account the expected changes in consumer expediture patterns and input coefficients between 1971 and 1985. The 14 identified categories of personal consumer expenditures with significant projected increases were mostly metallic durables. Thus, the proportion of metals in the future household waste stream is expected to increase. The 1985 household stream is expected to continue to have a high proportion of waste related to paper and paperboard mill products, followed by ferrous waste resulting from steel production activity, with discarded glass comprising the third largest waste component. The projections of future production and consumption activities provide indications of the recyclable materials that can be expected in the future household waste stream.

17. KEY WORDS AND DOCUMENT ANALYSIS

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of the environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report focuses on the rate at which solid waste is accumulating, and projects the size and composition of the future household solid waste stream based on trends in industrial production and consumption patterns. It is hoped that the research results will be useful to policymakers and others in formulating plans for coping with future solid waste management problems.

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ABSTRACT

Previous approaches to the analysis of household solid waste have involved mainly studies of the composition of waste samples in particular communities. A few attempts have been made to base estimates on the production or consumption data for the whole U.S. economy. The latter are precursors to the approach undertaken in this study, but differ in several respects. A major deficiency of the earlier attempts to infer waste composition from economic data was the lack of capability to show the consequences of possible changes in the structure of the economy. A related deficiency was the comparative invisibility--hence, unverifiability---of the assumption on which the estimates were based.

The input-output approach employed here provides a means of testing the consequences of postulated (and projected) changes in government policy or industrial technology. In effect, the input-output method infers not only what quantities of particular materials can be expected in household solid waste but why these materials can be expected, as the model is based on the structural interdependencies of producing and consuming sectors in the economy. A clear understanding of the structural interdependencies is necessary for the forecasting of future changes which cannot be accurately predicted by extrapolation. This research concentrated mainly on the first of two essential steps--that of developing a highly detailed analysis of the material flows which define the interdependencies. Because of resource restraints, only a limited effort was

devoted to adjusting the analysis for possible technological and other events which are not reflected in the projection of current trends.

The quantity and composition of household solid waste was forecasted up to 1985. Using the INFORUM model, projections of selected industry sector productivities and subsequent household waste quantities were made, taking into account the expected changes in consumer expenditure patterns and input coeffficients between 1971 and 1985. The 14 categories of personal consumer expenditures projected to increase most significantly are nearly all durables and are largely made of metals; thus, the proportion of metal in household waste can be expected to grow in the future. In 1985, the household waste is expected to continue to have a high proportion of waste generated by paper and paperboard mills. Ferrous waste is expected to account for the second largest component, followed by discarded glass products. Comparing the inputs of industrial sectors for 1971 with inputs for 1985, the largest growth is for plastic materials. Large proportionate increases are expected in the use of rubber, glass, aluminum, and other metals. The input-output model estimates are for inputs and do not necessarily represent composition of wastes as disposed of. These are obtained by extrapolation based on estimates of the average life of the various end products.

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OVERVIEW OF REPORT

Chapter 1

- Reviews previous methods of solid waste estimation.
- Identifies four types of studies:
    - Surveys of municipal waste loads per capita
    - Composition studies of household waste samples
    - Estimates based on economic production data for goods used by households
    - Estimate based on economic data for consumer purchases
- Discusses advantages and limitations of each of these approaches.
- Discusses potential advantages and limitations of the input-output approach, emphasizing the inherent strength of a method which utilizes a large body of sound historical data.

Chapter 2

- Describes input-output models and how they define the structure of the economy in terms of flows of material and flows of money.
- Shows how the input-output model is based upon a set of accounts representing transactions between different sectors of the economy; and shows how these accounts are balanced to produce a consistent input-output table.
- Shows that when the table has been balanced, material inputs can be used as a measure of material output by sector, as determined by the actual structure of the economy, rather than as indicated by surveys, spot checks, or production data which do not specify where the materials are being used.
- Shows the principal assumptions upon which the model's definition of the inter-industry relationship in one economy are based, including the assumption that the relationships are not assumed to be constant over time, but define the

pattern of sales which exist at a specified point in time as represented by a table of coefficients.

- Describes the inverse matrix, which converts the patterns of sales into coefficients of demand for particular materials by particular sectors, by "cumulating" both direct and indirect demands, so that when a change in productivity occurs for a consuming sector, one effect on the amount of material produced by the selling sector may be calculated for each material occuring in household waste.
- Discusses the usefulness of the input-output model in general, emphasizing its value in delineating the structure of the economy and the patterns of dependence among industries, as opposed to forecasting changes in economic variables.
- Shows how patterns of purchases can be used to infer patterns of waste production, through analysis of the extent to which particular materials are "embodied" (i.e., carried along physically) in particular kinds of purchases (in this case, consumer purchases).
- Suggests that an accurate estimation of household waste must incorporate (1) techniques of adjusting for substantial amounts of non-embodied inputs, and (2) techniques of distinguishing other forms of waste including industrial and commercial waste, as well as for other factors to be examined in Chapter 3.

Chapter 3

- Gives more detailed discussion of the adjustments which appear necessary to derive estimates of household waste from input-output data, beginning with a "method of minimal adjustment" showing what can be accomplished simply by adjusting for the two factors (embodied inputs and industrial/commercial waste) discussed in Chapter 2.
- Lists the assumptions which appear (based on an initial appraisal) to be implicit in the method of minimal adjustment and showing how these assumptions may be sources of significant error

for which further adjustments may be necessary.

- Shows how these assumptions can be tested and appropriate adjustments made if necessary. While this initial appraisal deals with five possible sources of error, it strongly suggests that one, in particular--the assumption that the coefficients of the input-output model correspond to the actual flows of materials--must be given careful attention in the ensuing analysis.
- Introduces the concepts of "paths" (sequences of material flows from an originating sector through other sectors to final demand) and "path products" (products of the coefficients of sales of a particular material along a particular sequence).
- Shows how path products can be used to analyze the sensitivity of any industry to changes in final demand by incorporating not only the direct impacts shown by the inverse matrix, but the indirect inpacts represented by sequences of two or more steps.
- Shows that one way to test the assumptions of the method of minimal adjustment, and to identify errors in the model, is to test the paths empirically. As the testing proceeds in this study, it becomes increasingly evident the most critical errors are likely to be "aggregation" errors resulting from the assumption that the flows of a material from an industry to each of its purchasers will be proportional to (and can be prorated in accordance with) the fraction of that industry's total sales flowing to that purchaser.
- Distinguishes between predictive and structural accuracy of the model, and shows that structural errors are of concern if they reduce the capacity of the model to answer questions about contingencies, even if such errors do not necessarily result in wrong forecasts.
- Describes a method for identifying cases in which prorating errors are possible, and for avoiding prorating errors resulting

from the multiplication of path products representing aggregations of different materials which may be consumed in different proportions by the purchasing sectors.

- Shows how path products can be "truncated", i.e., how products which account for very small fractions of the final demand for a product can be eliminated without weakening the capacity of the model to show all of the significant dependencies in the economy.

Chapter 4

- Provides estimations of the amount and composition of household waste for the base year 1971, using the input-output model described in Chapter 2 and the adjustments discussed in Chapter 3.
- Describes the procedures used to derive the physical weight of materials.
- Describes the procedures used to allocate 1971 production by weight to various end products--with allowances for non-embodied inputs, industrial waste, and commercial waste; and with adjustments for double counting which tends to occur as materials become embodied in successively different products in a sequence (or path) leading to final consumption.
- Displays the proportion of each material that is purchased (hence disposed of) by consumer households, along with the proportion which must be considered "uncertain" because of the aggregated nature of the data for certain sectors.
- Displays the amount of material by end product that is purchased (and eventually discarded) by households.
- Compares the results of the present analysis upon other studies, showing that the input-output approach provides greater detail and greater capacity for sensitivity analysis.
- Provides detailed justifications for the adjustments to the model (as hypothetically described in Chapter 3 and actually applied here) required to derive estimates of household waste from the input-output data.

- Analyzes the relative importance of the various adjustments required, showing that the composition of solid waste cannot be obtained directly from an inverse of the Embodied Submatrix.
- Provides a critique of the input-output model, based on the adjustments made and results obtained for the study. This critique includes:
    1) A summary of the limitations and capabilities of the input-output model as a tool for estimating household solid waste output.
    2) A delineation of four different methods of using input-output models involving successive degrees of difficulty. One of these methods is a distinct alternative to that which has been used in this study.
    3) Discussion of how the study introduces techniques that permit detailed scrutiny of its own methods and assumptions.
    4) Discussion of the advantages of this approach to EPA.
    5) Discussion of a critical weakness in the input-output model which poses a need for major adjustments not only for the estimation of household waste, but also in all other uses of the input-output model. This discussion involves a further expansion of the earlier concern (first noted in Chapter 2) with the problem of aggregation (or prorating) errors.
    6) Discussion of the implications of this study for possible future changes in the rules and procedures by which input-output tables are constructed.

Chapter 5

- Provides projections of Personal Consumption Expenditures (PCE) as developed for the INFORUM model, with detailed results presented in Appendix D.

- Lists the categories of PCE forecasted by these projections to increase most significantly from 1971 to 1985.
- Provides macro projections of economic and demographic indicators from which personal consumption is derived.
- Reviews the relationship between macro projections and the more detailed projections of the input-output model, showing the dependence of the detailed projections upon the macro projections.
- Analyzes the projections of productivity in INFORUM, showing that the method of measurement may be questionable.
- Provides a critique of macro projections, showing that they fail to consider many specific changes in the economy for which information is available.
- Describes the methods by which changes in input-output coefficients over time can be made.
- Provides forecasts of household solid waste to 1985, based on the changing input-output coefficients.
- Discusses the role of EPA's Strategic Environmental Assessment System (SEAS) in estimating solid waste, and the relationship of the present study to SEAS.
- Provides a critique of long-range forecasting efforts in general, clarifying the distinction between (1) predicting the future and (2) analyzing the structure of the economy so as to show how various contingencies, were they to occur, would change various projections based on extrapolation of trends.

INTRODUCTION

THE NEED TO APPLY INPUT-OUTPUT TECHNIQUES TO HOUSEHOLD WASTE FORECASTING

Under the Solid Waste Disposal Act as amended by the Resource Recovery Act of 1970 Congress found

> "that the continuing technological progress and improvements in methods of manufacture, packaging, and marketing of consumer products has resulted in an ever-mounting increase, and in a change in the characteristics, of the mass of material discarded by the purchaser of such products;" and
>
> x x x
>
> "that the failure or inability to salvage and reuse such materials economically results in the unnecessary waste and depletion of our natural resources..."

The legislation set forth among its purposes promoting resource recovery systems, providing help to state and local governments in planning and developing resource recovery, and promoting a national research and development program for new and improved methods of separation, recovery and recycling of solid wastes. It expressly defined "recovered resources" to include both materials and energy to be recovered from solid wastes. The statute further authorized the Environmental Protection Agency (as successor to the Department of Health, Education, and Welfare) to conduct or support research relating to the identification of solid waste components and potential materials and energy recoverable from such waste components."

The continually growing quantity of solid waste generated by American households has been an enigma to environmental managers, despite various attempts to analyze it. On one hand, the nature of this waste seems as familiar as the contents of the households which produce it. On the other hand, a growing need for the recovery of valuable resources has led to a realization that much too little is known about the quantities of specific materials to be found in in this waste--and about the factors which may be expected to cause these quantities to change in the future.

The study described in this report represents a new approach to the analysis of household solid waste. Carried out under the auspices of EPA's National Environmental Research Center in Cincinnati, its purpose is to provide a method by which not only the current materials composition of this waste, but also the effects of new government policies or other significant developments on this composition--and on the possibilities for resource recovery--can be readily ascertained.

This approach involves the use of economic input-output analysis as a means of tracing the flows of physical materials from the household sector where they are last used, back to the industries from which they (or the products of which they are a part) are purchased. This analysis is based on a matrix that shows the values of purchases by every sector of the economy from every other sector during a given time period. From such a base, a dynamic model may be developed to show the levels of future purchases, sector-by-sector. By converting the values of purchases into the weights of basic material inputs, it is then possible to infer the kinds and quantities of materials embodied in the products discarded by households.

Previous approaches, as described in Chapter 1, have ranged from composition studies of sample waste in particular communities to estimates based on production or consumption data for the whole U.S. economy. The latter are precursors to the present approach, but differ from this approach in several respects. A major deficiency of earlier attempts to infer waste composition from economic data is their essential lack of capability to show the consequences (for waste composition and resource recovery) of possible changes in the structure of the economy. A related deficiency is the comparative invisibility--hence, unverifiability--of the assumptions on which the estimates they produce are based.

The input-output approach provides a means of testing the consequences of postulated (as well as projected) changes in government policy or industrial technology, since it is based on the structural interdependencies of producing and consuming sectors rather than on the analysis of discrete physical samples or sales data. In effect, the input-output method infers not only what quantities of particular materials can be expected to turn up in household waste, but why.

An understanding of structural interdependencies in the economy therefore facilitates the forecasting of future changes which cannot be predicted by extrapolation. Two steps are required: first, to develop a highly detailed analysis of the material flows which define these interdependencies; and second, to adjust this analysis for anticipated technological changes and other events which are not reflected in the projection of current trends.

The first of these steps is accomplished by the present study. Limited resources precluded the second step, partly because substantially more effort than originally expected was required to adjust the Commerce Department's basic data on the flows of money so as to correctly reflect the interindustry flows of materials.

In this study, the quantity and composition of household waste is forecasted to 1985, using the "corrected" structure of the economy (i.e., the economy as described in terms of materials embodied in products purchased by households) as a baseline, and employing the INFORUM model's extrapolations of inter-industry coefficients.

It should be noted that the detailed analysis provided here can serve as the methodological basis for dynamic forecasts in future applications, and that the most efficient possible way for EPA to use this method of estimation may be to apply it to the Solid Waste forecasting module of the Strategic Environmental Assessment System (SEAS), which is now incorporating a dynamic forecasting capability and which is directly linked to the STOCKS module showing the resource recovery implications of the forecasts.

It should also be emphasized, however, that for purposes of planning and implementing resource recovery systems, the need for forecasting waste generation may be less relevant than the need for delineating patterns of structural dependence among industries; so it may be less important to ask what percentage of household waste will be aluminum (for example) than to ask what percentage would be aluminum at a given point in time if certain policies affecting the materials composition of automobiles were instituted ten years earlier. In fact, this study demonstrates that it is possible for "true" forecasts to be generated by models which make totally false assumptions about the structure of the economy, and that such models make their users highly vulnerable to being misled about what to expect when the structure of the economy suddenly changes.

Because the validity of the model cannot necessarily be judged by its apparent accuracy, therefore, it is critically important to be able to examine not only the estimates generated, but also the complete set of structural assumptions and computational steps upon which they are based. The input-output approach, with its base of detailed interindustry data, makes it both possible and necessary to examine these assumptions and steps. Future applications will not require a duplication of the effort expended here, however, since this effort has enabled us to formulate a set of procedural rules by which the evaluation of assumptions is greatly expedited.

These procedural rules involve (1) the use of an inverse input-output matrix to estimate the direct and indirect effects of changes in demand for particular products on other industries (and on the production of materials which terminate in household waste); and (2) the analysis of "paths" (actual sequences of materials flow) to test, on a sector-by-sector basis, the assumptions of the inverse coefficients which allocate the flows of materials to various users.

In the course of this study, the internal visibility of the method by which input-output analysis generates estimates of waste was both exhilarating and frustrating for the researchers--and proved to be both a boon and a barrier in our attempt to achieve the full mandate of the project. On one hand, this visibility resulted in the discovery of a number of erronious assumptions which are implicit in the input-output method. As a result, it was necessary to make a number of major adjustments. On the other hand, this visibility also helped us to develop a critique of input-output methods which we believe may have consequences for EPA (as well as for other users) considerably larger than those the author of this report originally set out to explore.

CHAPTER 1

REVIEW AND EVALUATION OF LITERATURE AND CURRENT RESEARCH ON HOUSEHOLD SOLID WASTE GENERATION

The use of an input-output model to estimate the quantity and composition of household solid waste does not entail the application of new methodology so much as the integration of previously used techniques into a tool which is both more powerful and less expensive than its predecessors. These earlier techniques, as described below, are to some extent duplications of the effort which has already been expended in the development of the input-output tables upon which the model used in this study is based. A brief review of the methods by which industrial data has been used in other studies suggests that the use of available input-output data may provide a promising alternative, particularly in its capacity to make detailed allocations of basic materials to various finished products. The earlier studies, while apparently less capable of generating a complete analysis of the material flows which terminate in household waste, must nevertheless be regarded as precursors of the use of input-output analysis described in this report.

The developing literature on estimation of composition and weight of household solid waste, past, present, and future, can be evaluated in three general categories: analyses of waste loads transported and disposed of by municipalities, including composition studies carried out by hand-sorting grab samples from randomly selected households or loads of waste; estimates of current and future waste loads based on economic production data; and estimates based on consumer purchasing forecasts.

Prior to 1968, only scattered estimates of the quantities of wastes generaged by households were available. In enacting the Solid Waste Disposal Act of 1965, Congress had provided for grants to state and interstate agencies of up to 50 percent of the costs of conducting surveys of solid waste disposal practices and problems. By 1968, thirty-eight states, the District of Columbia, Puerto Rico and three interstate agencies had received planning grants, and had started or completed solid waste surveys following a study design and reporting format designed and coordinated by the U.S. Public Health Service. Data available on July 1, 1968 was published in its basic form.[1] The initial publication was followed by a second publication in a more concise statistical format.[2] Although widely distributed in this form, the final results of the completed survey were never formally evaluated or published. However, final figures have been analyzed and informally reported.[3] The partial analysis was presented at the October, 1968, meeting of the American Public Works Association.[4] Although the survey requested responses based on actual weights or measurements in cubic yards, most of the participating communities furnished estimates of the waste loads they handled. The results were summarized in the conclusion that household and commercial solid waste was generated at an average rate of 4.15 lbs per capita per day. Adding demolition, construction, industrial, yard trash and other municipal solid wastes to this figure raised the per capita figure to 5.32 lbs per day. The informal final 1968 data analysis estimated the residential, commercial and institutional total at 4.01 lbs per capita per day. Subsequent critical analysis showed that the relatively few communities that made actual measurements to comply with the National Survey requirements arrived at lower totals than communities that reported estimates.[5,6] An early effort to base waste estimation on material production data pointed out that if the values reported in the sample composition studies were reliable then the amount of paper waste that would be consistent with the 1968 Survey results would be greater than the estimates of paper entering the waste stream that are based on paper production data, even taking into account the fact that the production-based data was in dry weights and the 1968 Survey estimates would have included varying amounts of water.[7] Subsequent evaluation by F.A. Smith of EPA's Office of Solid Waste Management Programs has recognized these shortcomings and suggested that although the 1968 Survey results may have overstated waste flows, the subsequent analytical efforts have not yielded information on which to base a more accurate estimate.[8]

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[1] Muhich, A.J., A.J. Klee, and C.R. Hampel, 1968 National Survey of Community Solid Waste Practices, Public Health Service, Pub. No. 1866, Washington, D.C., U.S. Government Printing Office, 1968.

[2] Muhich, A.J., A.J. Klee, and P.W. Britton, Preliminary Data Analysis, 1968 National Survey of Community Solid Waste Practices, Public Health Service Pub. No. 1867, Environmental Control Administration, Cincinnati, Ohio, 1968.

[3] Britton, P., "Unpublished EPA analyses of final questionnaire returns received by the 1968 National Survey of Community Solid Waste Practices." Reported at p.4 of Smith, F.A., "The Quantity and Composition of Community Solid Waste: Comparative Estimates" unpublished paper, Resource Recovery Division, Office of Solid Waste Management Programs, U.S. Environmental Protection Agency, June, 1974.

[4] Black, R.J., A.J. Muhich, et al,"The National Solid Waste Survey: An Interim Report", Papers presented at the 1968 Annual Meeting of the Institute for Solid Wastes of the American Public Works Association, Miami Beach, Florida, October 24, 1968.

A subsequent, less comprehensive, survey done for the National Solid Waste Management Association in 1971 used volume data from major private waste collection organizations, as a basis for estimating the weights of waste collected per capita.[9] In general,the range of values

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[5] Resource Planning Associates, Inc., Potential Economic Value of the Municipal Solid Waste Stream, Report prepared for the National Center for Resource Recovery, Inc., September, 1972, Cambridge, Mass.

[6] "Municipal Solid Waste: Its Volume, Composition and Value," NCRR Bulletin, Vol. III, No. 2 (Spring 1973), National Center for Resource Recovery, Inc.

[7] Darnay, A., and W.E. Franklin, Salvage Markets for Materials in Solid Wastes, Solid Waste Management Series No. SW-29C, U.S. Environmental Protection Agency, Washington, D.C., Government Printing Office, 1972.

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[9] Applied Management Sciences, Inc., The Private Sector in Solid Waste Management: A Profile of Its Resources and Contribution to Collection and Disposal, Vol. 2: Analysis of Data, Washington, D.C., U.S. Environmental Protection Agency Report SW-51d, 1973.

estimated for commercial, demolition, industrial and other waste categories coincided with those in EPA's final analysis of the 1968 Survey results; but those for residential waste were approximately 30 percent higher.

More recently, EPA funded two studies in which residential wastes from 31 municipalities and counties were weighed. Preliminary residential waste estimates reported by F. A. Smith, are almost exactly in line with those reported in the final EPA evaluation of the 1968 Survey results.[8]

THE METHODOLOGIES OF HOUSEHOLD WASTE ESTIMATION

The most significant single drawback of the survey data discussed above, considered as a base from which to forecast future amounts of municipal wastes, is that regardless of the degree of accuracy of particular surveys, differences in samples, estimation techniques and assumptions are likely to account for differences among the results to a greater degree than differences in actual household waste generation warrant. For this reason, although the studies relate to 1967, 1970, 1971 and 1972, they cannot be treated as a time series. Standing alone, unlike a time series of production or consumption data, these surveys do not permit trend extrapolation through which to anticipate future waste levels. If the assumption is made that per capita solid waste output is a fixed value that is unaffected by such variables as changes in per capita income, packaging technology, or family size, then a value taken from these survey results could be multiplied by future population levels to arrive at an estimate of the weight of 1985 wastes. Because it can not yet be established that these and other variables will not have a major effect on amounts of waste generated, it is necessary to turn to other methods in order to improve upon EPA's capability to make long-range estimates of amounts of wastes generated by households.

Analyses of Municipal Waste

Both before and since the 1968 Survey, there have been a large number of analyses of the composition of household or municipal solid wastes. Representative examples include Oceanside, New York,[10] Cincinnati, Ohio,[11] Flint, Michigan,[11] Johnson City, Tennessee,[11] San Diego, California,[11] Berkeley, California,[12] Raleigh, North Carolina,[13] Santa Clara County, California,[14] Weber City, Utah,[11] New Orleans, Louisiana,[15] Alexandria, Virginia,[11] Atlanta, Georgia,[11] and Madison, Wisconsin.[16] There have also been several efforts to synthesize average or national composition figures from the many available samplings.[17-20] These studies customarily use such composition categories as food, yard wastes, glass, metal (sometimes broken out into ferrous and non-ferrous), paper, plastics, textiles, wood, leather and rubber. Variations among the recorded figures indicate that "average" composition may be a misnomer and that wide fluctuations in daily composition, varying by day of the week and month of the year, as well as by geographic location, are the norm.

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[10] Kaiser, E.R., "Composition and Combustion of Refuse," Paper at MECAR Symposium on Incineration of Solid Wastes, New York, March 21, 1967.

[11] Unpublished tabulation by Bureau of Solid Wastes, Public Health Service, "Physical Analyses of Solid Wastes by Weight."

[12] Golueke, C.G., and P.H. McGauhey, "Comprehensive Studies of Solid Wastes Management," First Annual Report, May 1967, Sanitary Engineering Research Laboratory, College of Engineering and School of Public Health, Berkeley, California.

[13] "Evaluating Alternatives in Refuse Disposal," Progress Report, January 1, 1967-December 31, 1968, Department of Public Works, City of Raleigh, North Carolina, PHS Grant 1-D01-U1-00050-01-02.

[14] "Systems Analysis for Solid Waste Disposal by Incineration," FMC Corporation, November, 1968, The City of San Jose and the County of Santa Clara, California.

[15] Unpublished Report, City of New Orleans, Louisiana, "Solid Waste Disposal-Tri-Parish Areas," May 15, 1968, New Orleans, Louisiana.

[16] Reinhardt, John, A Report on the Demonstration of a Grinding Mill for Pulverizing Refuse and Landfilling Milled Refuse without Daily Cover, Final Report under U.S. Department of Health, Education, and Welfare Grant No. 5-D01-U1-0004.

The composition studies have been very helpful in previous estimation work aimed at identifying the resource potential implicit in national waste flows.[8,21] However, to an even greater degree than the surveys, each of the composition studies must be considered one point in its own discrete time series. Data from different places, collected over a short period of time and under conditions suggesting major seasonal and even weekly changes in composition, can not be used as a base from which to extrapolate long term change.

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[17] Niessen, W.R., and S.H. Chansky, "The Nature of Refuse," *Proceedings, 1970 National Incineration Conference*, New York, N.Y., Soc. of Mechanical Engineers, pp. 1-24.

[18] Niessen, W.R., and A.F. Alsobrook, "Municipal and Industrial Refuse: Composition and Rates," *Proceedings of 1972 National Incineration Conference*, New York: Am. Soc. of Mechanical Engineers, 1972.

[19] Niessen, W.R., *et.al.*, *Systems Study of Air Pollution from Municipal Incineration*, Final Report under contract CPA-22-69-23 to the National Air Pollution Control Administration, Arthur D. Little, Inc., Cambridge, Massachusetts, March, 1970.

[20] Drobny, N.L., H.E. Hull, and R.F. Testing, *Recovery and Utilization of Municipal Solid Waste*, U.S. Environmental Protection Agency, Publication No. SW-10c, 1971.

[21] Humpstone, C.C., R.S. Cortesi, I. Gutmanis, S.B. Noble, *et al*, *Problems and Opportunities in Management of Combustible Solid Wastes*, Final Report by International Research and Technology Corporation to the National Environmental Research Center, Cincinnati, Ohio under U.S. Environmental Protection Agency contract No. 68-03-0060, National Technical Information Service, No. P.B. 222 467, Washington, D.C., August 1973.

Estimates Based on Production Data

The need for greater predictive capabilities, as well as other factors (such as the possibility that extrapolations from survey results may lead to unreliable results because of the difficulty of handling such variables as moisture content) has led to an increasing interest in the use of industrial production statistics as a source of data from which to estimate the amounts and composition of household wastes. The approach has been called "input" estimation, to distinguish it from collection-based "output" oriented surveys. (The terms so used should not be confused with the phrase "Input-Output" used in this report to describe the form of economic analysis that has developed by Wassily Leontief during the 1930's.)

The best known of the early input studies were the studies of packaging materials and non-packaging paper by Darnay and Franklin[22,23] of Mid-West Research Institute. These have been followed by successor MRI studies.[24,25,26] Resource Planning Associates, Inc. has also started from

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[22] Darnay, A.J., and W.E. Franklin, The Role of Packaging in Solid Waste Management 1966-1976, Pub. No. SW-5C, U.S. Department of Health, Education, and Welfare, Bureau of Solid Waste Management, Rockville, Maryland, 1969.

[23] Franklin, W.E. and A.J. Darnay, The Role of Non-Packaging Paper in Solid Waste Management 1966 to 1976, Pub. No. SW-26c, U.S. Environmental Protection Agency, Solid Waste Management Office, Washington, D.C., Government Printing Office, 1971.

[24] Darnay, A.J. and W.E. Franklin, Salvage Markets for Commodities Entering the Solid Waste Stream, U.S. Environmental Protection Agency, 1973.

[25] Franklin, W.E., Paper Recycling: The Art of the Possible, American Paper Institute, 1973.

[26] Franklin, W.E., Hahlen, D., Park, W.R., Urie, J.M., Base Line Forecasts of Resource Recovery, 1972 to 1990, Review Draft Final Report, MRI Project No. 3736-D, Office of Solid Waste Management Programs, Environmental Protection Agency, Washington, D.C., 1973.

industrial production data to arrive at waste generation estimates.[27] Comprehensive reviews and evaluations of the earlier work were prepared by Frank A. Smith and Fred L. Smith, Jr., of EPA's Office of Solid Waste Programs, in June of 1974.[8,28] These reviews preceded the Smiths' own estimates of national totals and per capita daily average waste production as well as of waste composition. In each study using this approach, bulk production data on materials is corrected for imports and exports to yield an estimate of bulk consumption. This estimate is corrected for process losses and for imports and exports of the relevant finished goods. (The factor of process loss is important in input analyses of solid waste generation because it indicates the percentage of material that does not continue on to become part of the final consumer product.) The consumption estimates produced are allocated by end-use to determine the quantities of materials entering the relevant waste stream. This step, for example, determines what fraction of paper board will end up as industrial plant trash, as discarded bulk containers in commercial waste, and as household waste. This allocated consumption data is lagged to account for the durability of each category of end use products. In each of these final use categories the amount of material recovered is subtracted to yield an estimate of solid waste for that category.

There are several difficulties implicit in this form of analysis. Time lag estimation is a difficulty that is also common to the other classes of analyses discussed below. There are actually two sets of time lags. The first is the lag between production and consumption, during which a product is in the distribution system. The second is the lag between purchase and discard. Although rational methods for developing time lag assumptions for both kinds of lags can be developed and defended, they will necessarily rely in large part upon intuitive processes. It may be reasonably safe to assume that all packaging materials used in packaging consumer products enter the waste stream within a year of their production. It may be less safe to assume that small appliances enter the waste stream at a rate equivalent to the production output of a past year (selected by consulting product life expectancy data), or that rate of disposal of all textiles used in clothing can be assigned a single "average" lag rate. (The input-output method with which this report deals is particularly vulnerable to lagging difficulties since this method does not provide any means of using past production data in conjunction with varying life expectancy rates for different products.)

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[27] Resource Planning Associates, Inc., Potential Economic Value of the Municipal Solid Waste Stream, Report prepared for the National Center for Resource Recovery, Inc., September, 1972, Cambridge, Massachusetts.

[28] Smith, F.L., Jr., "Estimates of Household and Commercial Solid Wastes Based on Production Statistics," unpublished paper, Resource Recovery Division, Office of Solid Waste Management Programs, U.S. Environmental Protection Agency, June, 1974.

A second more fundamental difficulty with the production data approach (but not of the input-output approach) is the need to know not only how much of a given material is produced but also for what it is used. Polyester fiber may be used in cordage, automobile upholstry, and electric cable insulation, as well as in textiles incorporated into clothing. The nature of the use will determine whether a material ends up in automobile scrap, demolition waste, or household waste. It will also determine the lag time, which varies widely with different end uses.

For every major component of the waste stream, it is necessary to determine the weight of material sold by its producers to all manufacturers of products or materials destined for sales to consumers. For some materials, such as glass bottles, such data is readily available; for others it is not. One of the inherent advantages of the input-output method used in this study is that a large body of work has already been done (in the development of input-output tables) to trace the flows of materials from raw materials to final consumption.

Waste estimation based on production data has a significant advantage over survey-based estimates, in that time series data is available upon which to base a forecasting procedure. However, while such time series will be useful for short range forecasts, they cannot be used for long range estimation. Extrapolation from past production will not be a reliable indication of probable future concentrations of tinned steel, aluminum, or bi-metal cans; metal foil; blass; paper; or plastic containers in the packaging of consumer products. To develop such an indication requires an independent reconciliation of the competing claims of materials that can be substituted for one another. Such reconciliations are also inherent in the structures of existing input-output models.

Estimates Based on Consumer Purchasing Forecasts

Two waste forecasting efforts have sought to utilize consumer expenditure forecasts to improve upon the degree of detail available for incorporation into projections of forecasting. A detailed analysis of consumer spending patterns was carried out by URS Research Company to permit the analysis of waste generation.[29,30] Two models were developed: one for the prediction of residential solid waste generation, and the other for the prediction of commercial solid waste generation.

In the residential model, total retail expenditures are collected in a regional data bank showing the 1960-61 distribution of household spending over 700 items. Analysis of this data shows the amount spent by households on each consumer item during the period of time sampled (usually one week). The number of items purchased is then derived from the price per unit for each consumer item. From the number of items purchased and a listing of the physical weight and composition of each item, an inventory of waste materials is generated.

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[29] G.B. Boyd and Hawkins, J.B., Methods of Predicting Solid Waste Characteristics, URS Research Company, interim report prepared for the U.S. Environmental Protection Agency, Bureau of Solid Waste Management, San Mateo, California, 1971.

[30] R.A. Black, Fielder, R.R., Hawkins, M.B., Strom, P.O., A Planning Model for the Prediction of Residential and Commercial Solid Wastes, URS Research Company, Final Report prepared under contract to the U.S. Environmental Protection Agency, Office of Solid Waste Programs, 1972.

The commercial model is similar insofar as it used the sales of merchandise (prorated to the specific items) and the unit price per item, to determine the number of items sold. It then estimates total commercial (retail activity) waste assuming a standard waste composition for each item. It has identified discarded shipping containers as a major component of commercial waste.

This model, as ultimately developed, was oriented toward a rapid through-put of materials. Standing by itself, it would not project future solid waste generation. The interim report on the project described the procedures for dealing with projections using such variables as retail expenditures, distribution of household expenditures, price per unit by item, and physical description of each item. An endogenous estimate for each was required in order for the model to produce a projection. The interim report also discussed the need for separate models to deal with products associated with short versus long periods of residence.

Other attempts to use forecasts of the future consumer environment to anticipate the amounts and composition of household packaging wastes have been made by the Research Triangle Institute.[31] These attempts involved a straightforward method for the estimation of future packaging waste. The weight of consumer packaging per dollar of consumer expenditure (for each of 30 categories of consumer products) was determined for 1958-70 and extrapolated linearly to 1980. Econometric projections of personal consumption expenditures were made to determine the 1980 expenditures for each product category. The methodology of economic projections will be discussed in Chapter 5.

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[31] An Evaluation of the Costs of Effectiveness of Regulatory and Fiscal Strategies on Product Packaging, Research Triangle Institute, report prepared for the U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, draft final report, 1973.

From the 1980 weight of packaging per dollar and the 1980 expenditure, a value for the total weight of 1980 packaging was determined. This value and an estimate of the materials distribution in packaging yield the amounts of particular materials used in packaging in 1980 for each product category assuming that packaging materials become solid waste within a year.

These consumer forecast-based studies constitute an important conceptual advance over the industry production studies, in that they take advantage of an internally consistent set of forecasts about future levels of consumption and production. In general, these forecasts are in turn based upon an adequate body of time-series data. However, the forecast-based studies are conceptually deficient in their handling of product composition, either in fixed product composition estimates or in linear extrapolation of product composition change from past composition trends. And, like the production data studies described earlier, these studies fail to deal adequately with the lag times between purchase and disposal.

A Composite Forecasting Method

An earlier study by International Research and Technology Corporation undertook to apply all of these methods to the task of forecasting the amounts, composition, and location of future (through 1980) loads of combustible wastes from all sources.[21]

Livestock wastes were estimated by utilizing data on manure production per animal and forecasts of future animal populations based on future consumer expenditure forecasts. Crop waste estimates were derived from data on regional crop production and on waste generation and disposition by crop. Industrial combustible wastes were forecast based on an input-output model, which customarily describes flows of materials and products in terms of dollar sales. These were converted, using price data, into flows of physical quantities. Industry sources and the literature were surveyed to obtain estimates of the amounts and composition of process waste and plant trash (mostly miscellaneous packaging waste) generated per pound of output and waste generation trends. These data were converted into waste coefficients and applied to the model's forecasts of future outputs so as to yield forecasts of industrial process wastes. The analysis was also regionalized, using data on industry locations.

Because of the lack of regional consumer purchase forecast data, no input-output analysis of household waste was attempted. Instead household waste generation forecasts were estimated by using per capita waste production figures derived from the 1968 Survey and future population distribution figures. Thus, while stopping short of applying input-output analysis to household waste prediction, this study nevertheless marked the first formulation of input-output analysis as a tool for the development of waste management policy.

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30. R.A. Black, Fielder, R.R., Hawkins, M.B., Stron, P.O., A Planning Model for the Prediction of Residential and Commercial Solid Wastes, URS Research Company, Final Report prepared under contract to the U.S. Environmental Protection Agency, Office of Solid Waste Programs, 1972.

31. An Evaluation of the Costs of Effectiveness of Regulatory and Fiscal Strategies on Product Packaging, Research Triangle Institute, report prepared for the U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, draft final report, 1973.

CHAPTER 2

THE INPUT-OUTPUT MODEL

Input-output analysis provides an alternative to the methods described in Chapter 1. This alternative, as will be seen, is by no means capable of providing push-button forecasts. Nevertheless, there appear to be several major potential advantages to EPA in the use of this approach. Some of these advantages (along with some clear limitations) are inherent in the method, as will be seen. Another kind of advantage may come from the fact that EPA has already made substantial investments in one use of an input-output model (in its SEAS program) for other purposes, and therefore has access to a form of industrial data which would be prohibitively expensive to reproduce in any ad-hoc study of household waste.

This chapter describes the input-output model (as used in this study) in general terms, showing how such a model can be used to infer patterns of waste production.

FLOWS ASSOCIATED WITH AN INPUT-OUTPUT MODEL

The previous chapter discusses the opportunity to use commodity flows as a basis for waste estimation. An example is given in Figure 2.1, which shows the sequence in which iron ore is converted to steel, which is in turn used to make parts that are assembled into motor vehicles. The input-output model is concerned with a different type of flow in an economy, the flow of money.

Flows of money can be thought of as starting with household consumers (Figure 2.2) who demand finished goods, such as house trailers and motor vehicles, in exchange for their money. Since this demand can be expected to continue--additional consumers are going to purchase similar products in the future--the firms which manufacture these goods make comparable

FIGURE 2.1

SOME FLOWS OF MATERIALS

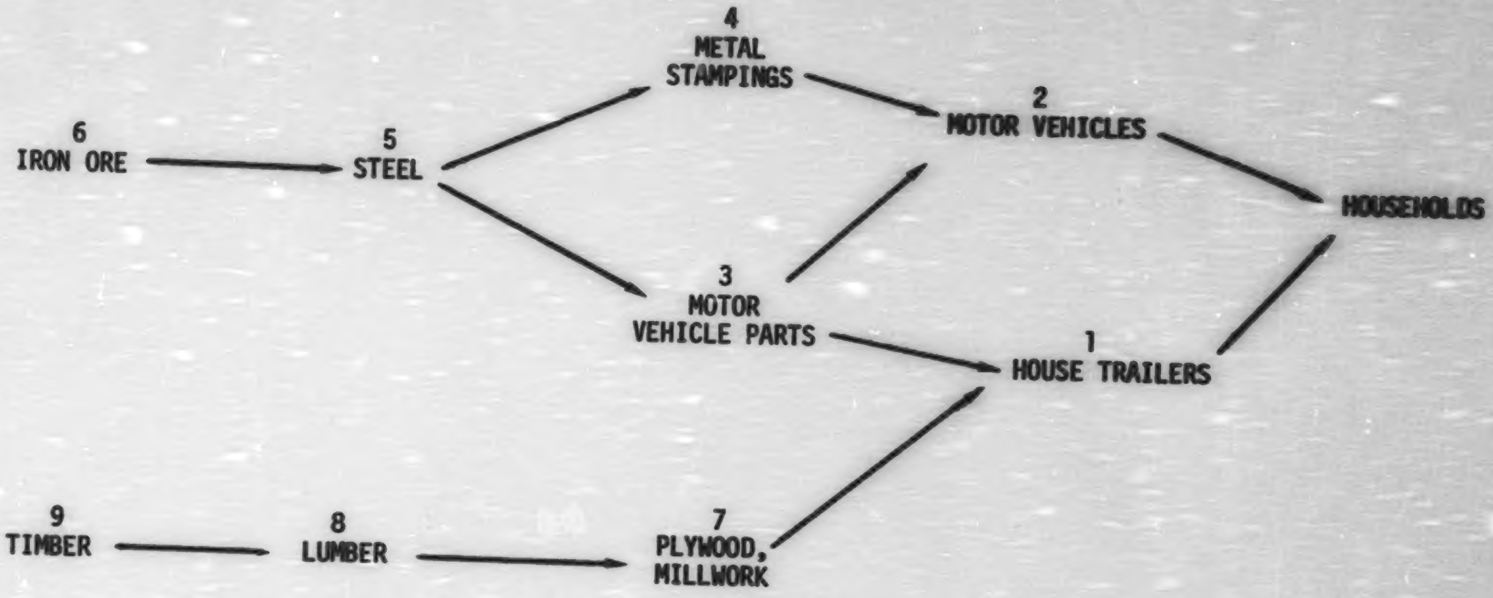
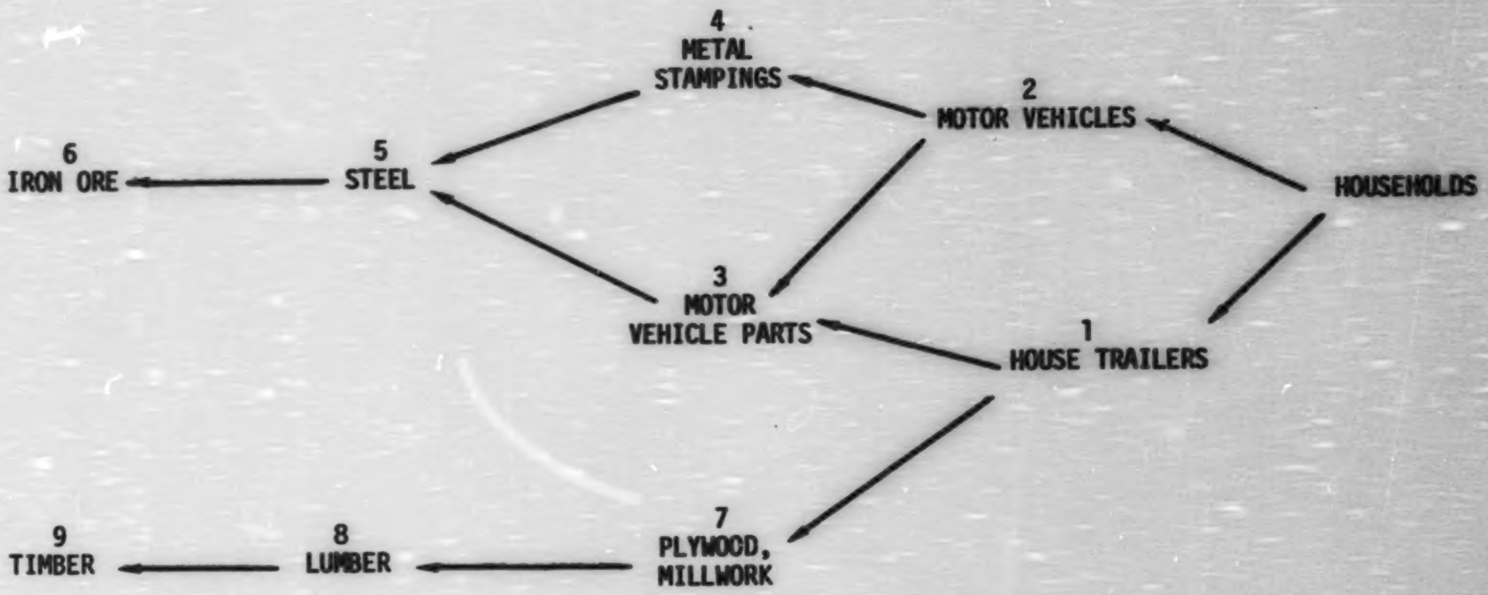

4
METAL
STAMPINGS
2
MOTOR VEHICLES
6
IRON ORE
5
STEEL
HOUSEHOLDS
3
MOTOR
VEHICLE PARTS
1
HOUSE TRAILERS
9
TIMBER
8
LUMBER
7
PLYWOOD,
MILLWORK

FIGURE 2.2

SOME FLOWS OF MONEY


HOUSEHOLDS
2
MOTOR VEHICLES
1
HOUSE TRAILERS
4
METAL
STAMPINGS
3
MOTOR
VEHICLE PARTS
7
PLYWOOD,
MILLWORK
5
STEEL
8
LUMBER
6
IRON ORE
9
TIMBER

demands on their suppliers. Thus, the motor vehicle manufacturers purchase stamped fenders; the manufacturers of fenders purchase additional steel; and steel mills and blast furnaces contract to purchase iron ore. If inventories of inputs are continually replenished, then the demand for finished goods is transmitted into a demand for raw materials.

Additional sequences begin with capital expenditure. Firms either borrow money or utilize their own cash in order to pay for plants and equipment. The firms that receive orders for capital equipment must in turn purchase parts, metal shapes, and construction materials. The firms that supply these must replenish their inventories if they are to remain in business, and so some of the money paid to these suppliers is then passed on to the suppliers of raw materials such as ores and sand. Each step of the way, some of the money is paid to workers as wages and salaries or is kept as depreciation or retained earnings. The amount of money flowing toward a particular raw material is reduced at each step because of its further dispersal to other industries and employees.

When money flows through the economy, goods and services flow in the opposite direction. Figure 2.2 shows flows of purchases, while Figure 2.1 shows sequences of sales. The two figures are identical except for the direction of the arrows. Thus, flows can be looked at two ways: as purchases or as sales. We have our choice as to which to use. By tracing purchases, we are able to pursue the effects resulting from changes in demand as they are transmitted back through an economy. In tracing sales, we are not only tracking the physical movement of goods and services, but also defining the indirect demands for which production occurs.

This report will consistently use the following convention: the direction of an arrow represents sales, as in Figure 2.1. These flows will be derived from an input-output table and will represent monetary transactions. However, the direction of flow will be in the direction that goods flow, this being opposite to the direction in which money flows.

TABLE 2.1

PART OF AN INPUT-OUTPUT TABLE (x 10^{-6})

	1 House Trailers	2 Motor Vehicles	3 Motor Vehicle Parts	4 Metal Stampings	5 Steel	6 Iron Ore	7 Plywood, Millwork	8 Lumber	9 Timber	Households
1 House Trailers										
2 Motor Vehicles										
3 Motor Vehicle Parts	239	18,964								
4 Metal Stampings		4,293								
5 Steel			4,534	942						
6 Iron Ore					1,516					
7 Plywood, Millwork	429			54	18					
8 Lumber	88				22		1,722			
9 Timber								1,520		

Amounts less than $10 million omitted.

DERIVATION OF THE INPUT-OUTPUT MODEL

The Input-Output Table

The input-output model is based upon a set of accounts which can be represented by a table. An example is Table 2.1 which corresponds to the diagrams shown in Figures 2.1 and 2.2. As this table indicates, the steel sector sells its product to the motor vehicle parts and the metal stampings sectors, and, in turn, each of these sectors sells to the motor vehicles sector. In accounting terminology, this type of table is called a "spread sheet".* Each term is listed once but is a part of two accounts by being a debit (purchase) of one account and a credit (sale) of another. A sale of steel to motor vehicle parts is a credit for the account of steel and a debit for the account of motor vehicle parts.

Table 2.1 is only part of an input-output table. An input-output table represents all accounting transactions in an economy--all sales of steel, plywood, lumber, etc. Construction of an input-output table requires three steps:

(a) Grouping all establishments into industries.

(b) Listing the amount of transactions of each industry to each other industry during some time period. These transactions are arranged in a table where the horizontal rows represent transactions of the industry and the vertical columns represent its purchases.

(c) Balancing the accounts of each industry.

The third step, balancing the accounts, is a process which contributes markedly to the reliability of the numbers in an input-output table. The balancing of accounts is effectively accomplished at two levels. On the first level the value of the individual term t_{ij} i.e., a transaction representing the sales of industry i to j, is separately estimated by (1) a research team responsible for tracing the disposition of all *outputs from industry i*, and (2) a research team responsible for determining the sources of all *inputs to industry j*. The two calculations must then be "resolved"--i.e., the sale from i to j and the purchase of j from i must be adjusted until they are identical--before the value of the transaction can be incorporated into the interindustry totals which comprise the input-output table.

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*See Kohler, Eric L. A Dictionary for Accountants. 2nd Edition. Prentice-Hall, Inc., Englewood Cliffs, N.J., 1957.

On the second level, estimates of the total sales of each industry are obtained and the sum of the allocations (sales allocated to specific sectors) must be reconciled with each total. On both levels the effect is that information sources and assumptions must be extensively re-worked and reconsidered before the independently derived estimates can be reconciled satisfactorily. Flow patterns which are not apparent in an analysis of inputs to j will often be revealed by cross-checking with an analysis of the outputs of i--and vice-versa.

Input-output tables of the U.S. economy have been prepared for each year since World War II that there has been a Census of Manufactures: 1947, 1954, 1958, 1963, and 1967. Over the years, the balancing process has given the input-output tables a strong empirical foundation compared to estimates obtained by viewing transactions from only one side (i.e., purchasing or selling).

If the input-output accounts are to be balanced, it is necessary to take into account *all* categories of sales to (or purchases from) the included sectors. For revenue, accounts are introduced that show sales to foreign countries, households, capital purchases, and changes in inventories. For expenditure, accounts are added to record depreciation, taxes, and profits.

Any row of an input-output table can be represented by an equation of the following kind:

$$t_{i1} + t_{i2} + t_{i3} + \ldots\ldots + f_i = x_i \qquad (2.1)$$

t_{ij} is the sales of sector i to sector j,

f_i is the sales by sector i that go to final uses,

x_i is the total sales of sector i.

Any t_{ij} or f_i can be zero. x_i will always be positive (assuming that selection of industries is not done trivially).

The Assumptions of the Input-Output Model

The input-output model is obtained by making the following assumption:

$$t_{ij}/x_j = a_{ij} \text{ or } t_{ij} = a_{ij}\, x_j \qquad (2.2)$$

where a_{ij} is assumed to be a constant. The assumption is that the purchases of a sector (e.g., purchases of steel by motor vehicle parts) will increase or decrease in proportion to the output level of the purchasing sector (e.g., motor vehicle parts or metal stampings).

Combining equations (2.1) and (2.2) into one set of equations, we obtain

$$\begin{array}{ccccc}
(1 - a_{11})\, x_1 - a_{12}\, x_2 - \ldots\ldots\ldots\ldots & - a_{1n}\, x_n & = & f_1 \\
- a_{21}\, x_1 + (1 - a_{22})\, x_2 - \ldots\ldots & - a_{2n}\, x_n & = & f_2 \\
\vdots \quad \vdots & \vdots & & \vdots \\
- a_{n1}\, x_1 - a_{n2}\, x_2 - \ldots\ldots\ldots\ldots & + (1 - a_{nn})\, x_n & = & f_n
\end{array} \qquad (2.3)$$

This is the set of simultaneous equations of the input-output model.

The major limitation of the input-output model given in (2.2) is not its linear form, but its implicit assumption that inputs depend upon the level of production of the purchaser and upon nothing else. Such an assumption oversimplifies the dependencies in the economy. The purchases of inputs may depend upon many other variables such as relative prices, expectations of shortages, changes in fashion, environmental concerns and lawsuits, etc. Such factors have not been incorporated into the input-output model.

This assumption of proportionality is not imposed on all parts of the economy, however. Purchases by consumers, for example, are treated as exogenous to the model. This means that no assumption as to how consumers spend their income is made in the input-output model. It then becomes necessary to specify or forecast apart from the model the expenditure of consumers.

The terms f_i in equation (2.3) represent any portions of the economy for which assumption (2.2) does not apply. Besides consumer expenditure, this includes expenditures by governments and the balancing of national accounts: Capital purchases, international transactions, and changes in inventories. Expenditures of these types must be estimated apart from the input-output model (as discussed in Chapter 5). The assumption (2.2) is applied only to the productive part of the economy--current expenditures of manufacturing, mining, agriculture, and services.

It is important to emphasize that the coefficients of an input-output model are not assumed to be constant over time, but are assumed to be proportional at a point in time. For example, purchasing patterns which are dependent on the composition of an average automobile may change over time. Automobiles may become lighter because they may contain more aluminum, more plastic, and less steel. The input-output model accepts the convention that a coefficient pertains to a specific time interval (say, the year 1972), so that equation (2.2) becomes the following:

$$\frac{t_{ij}\ (1972)}{x_j\ (1972)} = a_{ij}\ (1972) \qquad (2.2a)$$

Chapter 5 discusses the methods by which changes of coefficients over time are predicted.

THE INVERSE OF THE INPUT-OUTPUT MATRIX

The data for input-output models is published in three different forms: As a table of transactions, a table of coefficients, and a table of the inverse matrix.* We have already been introduced to two of these forms:

Transactions	equation (2.1)
Coefficients	equation (2.3)

The assumption of (2.2) shows how to convert transactions into coefficients.

The third type of table, the inverse matrix, will be seen below to be useful in the analysis of solid waste. The inverse matrix may be elucidated by the following analogy:

The tables of an input-output model can be very large. Consider a model consisting of 100 industries, the input-output table would have 100 x 100 (i.e., 10,000) terms. In the simultaneous equations of (2.3), there would be 10,000 a_{ij}'s, 100 x's, and 100 f's. By using matrix notation, a set of simultaneous equations can be written very compactly. The equations of (2.3) become

$$(I - A)\ x = f \qquad (2.3a)$$

where; A is a square block of numbers n x n,

x is a set of n numbers, the industry levels, and

f is a set of n numbers, the purchases by final demand.

Recall that the set of numbers represented by A and f are specified, and we are then seeking to obtain a solution for x, the n industry levels.

If A and x and f were single terms, e.g., A = 2/3, then we would be able to carry through the following operations:

$$(1 - 2/3)\ x = f$$

$$1/3\ \ x = f$$

$$x = 3f$$

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*U.S. Department of Commerce, Input-Output Structure of the U.S. Economy: 1967, Three Volumes, Government Printing Office, Washington, D.C., 1974.

That is, we would solve the equation by forming the inverse of the term (1 - 2/3). A comparable operation exists for a square matrix, and the following equation can then be written:

$$x = (I - A)^{-1} f \tag{2.4a}$$

where $(I - A)^{-1}$ is the inverse of the matrix $(I - A)$.
Thus it is possible to compute an inverse matrix which, when multiplied by the set of numbers f, gives the set of numbers x.

The inverse matrix is the same size as the matrix A, or n x n. Let a single term of this matrix be b_{ij}. Then (2.4a) corresponds to the set of simultaneous equations

$$\begin{aligned}
x_1 &= b_{11}f_1 + b_{12}f_2 + \cdots\cdots\cdots + b_{1n}f_n \\
x_2 &= b_{21}f_1 + b_{22}f_2 + \cdots\cdots\cdots + b_{2n}f_n \\
&\vdots \qquad\qquad\qquad\qquad\qquad\qquad \vdots \\
x_n &= b_{n1}f_1 + b_{n2}f_x + \cdots\cdots\cdots + b_{nn}f_n
\end{aligned} \tag{2.4}$$

Our concern in this chapter is not how to compute the terms b_{ij} (that will be discussed in Chapter 3 below), but to understand what is meant by a term b_{ij}. That can be determined by considering the meaning of equations (2.4). Consider the term when i is steel and j is motor vehicles. The term b_{ij} would then represent the level of output of steel, x_i, that must occur because of the purchase of one unit of motor vehicles. Figure 2.1 shows some of the flows that must be taken into account. Each automobile requires the purchase of motor vehicle parts and metal stampings (as well as other inputs not cited in Figure 2.1), and each of these parts and stampings in turn require the purchase of steel (as well as other inputs not cited). The coefficient b_{ij} represents the sum of the demands by various sectors for steel resulting from their sale of parts for the production of a motor vehicle.*

Each term in the inverse matrix is an accumulator of direct and indirect demands. The term for steel-to-motor-vehicles equals the sum of all of the ways in which demand for motor vehicles will result in the requirement to produce steel. The set of all numbers in the inverse matrix is the set of all possible direct and indirect effects in the economy. According to Figure 2.1, purchases of motor vehicles have an effect upon motor vehicle parts, metal stampings, steel, and iron ore. The purchase of a house trailer has an impact upon all of these, as well as on millwork, lumber, and timber.

USEFULNESS OF THE INPUT-OUTPUT MODEL IN GENERAL

An input-output table is the result of the application of a specific set of rules for organizing and presenting a country's economic data. In some countries (e.g., Canada), input-output tables are constructed annually, and the U.S. Department of Commerce has recently begun to produce tables for each year dating back to 1967.

Let us consider the usefulness of such a table representing flows in an economy. By itself, it does not predict because it makes no assumption concerning large parts of the economy (i.e., final demand). Furthermore, it does not define relationships that are invariant over time, since the coefficients of the model are permitted to change with time.** What is accomplished, then, by constructing and publishing input-output tables?

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*Since household income and expenditures are not included in the matrix (I - A), the inverse does not include such effects as motor vehicle workers purchasing refigerators made of steel. Since the matrix does not include capital expenditures, the inverse does not include steel used in machinery of automotive assembly lines.

**Leontief refers to the economy as "in a state of constant flux" and goes on to say that "Without a constant inflow of new data the existing stock of factual information becomes obsolete very soon." Wassily Leontief, "Theoretical Assumptions and Nonobserved Facts", American Economic Review, Vol. 61 (1971), pp. 3 and 4.

One answer is that the reconciliation of data which is required for the construction of the tables is useful in the identification of gaps or inconsistencies between various bodies of data. The input-output model is also useful in delineating the structure of dependence in an economy. For example, the inverse matrix shows the market dependence between sectors, e.g., how the sales of steel will be affected if there is a change in demand for motor vehicles. The input-output inverse matrix also provides information regarding the cost dependence between sectors, e.g., how much of the cost of an automobile is due to the cost of steel.

By associating other equations with the equations of the input-output model, additional dependencies can be defined. For example, the level of employment in an industry can be expected to increase or decrease in accordance with the level of production. If we assume that this relationship is proportional--that the number of workers with skill i is proportional to the level of production, $e_{ij}\ x_j$ for each sector j--then the total number of workers of skill i employed in the economy, E_i, would be given by the following

$$E_i = \sum_j e_{ij}\ x_j. \tag{2.5}$$

Similarly, the level of pollution* of type i can be assumed to be proportional to output, $c_{ij}\ x_j$ for each sector j. It would follow that the total output of pollution of type i, s_i, would be equal to

$$s_i = \sum_j c_{ij}\ x_j. \tag{2.6}$$

Solid waste is treated here as a type of pollutant, and solid waste generated in industrial facilities can be estimated by equations such as (2.6).

Equations (2.5) and (2.6) can be combined with (2.4)

$$E_i = \Sigma\ \Sigma e_{ij}\ b_{jk}\ f_k \tag{2.7}$$

$$s_i = \sum_j \sum_k c_{ij}\ b_{jk}\ f_k \tag{2.8}$$

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*This approach is discussed more fully in Appendix A.

In matrix notation, we have

$$E = ex \tag{2.5a}$$

$$s = c\,x \tag{2.6a}$$

$$x = (I - A)^{-1}f \tag{2.4a}$$

$$E = e\,(I - A)^{-1}f \tag{2.7a}$$

$$s = c\,(I - A)^{-1}f \tag{2.8a}$$

In these cases, the input-output model again defines indirect dependence in an economy.

The input-output model, then, is able to provide contingent answers; its usefulness lies in the computation of scenarios that analyze what would occur in some parts of the economy (production, price levels, employment, pollution, etc.) if there were changes in other parts of the economy (consumer demand, exports, capital expenditure, import prices, etc.) during the period of time for which the model represents the known (or forecasted) structure of the economy.

Chapter 4 shows that the rules for construction of input-output tables are incompletely formulated, and that additional instructions could significantly improve the accuracy and usefulness of the input-output models.

USEFULNESS OF THE INPUT-OUTPUT MODEL IN THE STUDY OF SOLID WASTE

The central concern of this study is to determine whether the large amount of data in an input-output model of the U.S. economy can provide estimates of the amount and composition of household solid waste. At first glance, it would appear that the data in the input-output model is not appropriate since it represents purchases in an economy, rather than solid waste. Since physical materials generally survive the products in which they are used,* however, there is a connection between purchases of materials and the solid waste that is created when the materials are discarded. For example, the composition and weight of metal cans that are thrown out can be inferred from the composition and weight of metal purchased by the metal can industry.

It would appear, then, that input-output tables contain information that can be used to determine the amount and composition of household solid waste. However, the information in the input-output model needs to be adjusted if it is to be used for this purpose.

One required adjustment stems from the fact that the input-output model records inputs as values (price times quantity), whereas solid waste should be measured in units of weight. It will be necessary to develop methods of inferring the weight of inputs. It will also be necessary to adjust for any change of weight that occurs during production. In certain special cases, production can result in an increase in weight, e.g., a chemical process may acquire oxygen from the air which is combined with the inputs that are purchased. The more important case is that in which the production process reduces the weight of inputs when materials are cut or products are rejected. This produces industrial waste, and reduces the weight of the object which is sold to households and eventually discarded as solid waste.

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*See Ayres, Robert U. and Kneese, Allen V. "Production, Consumption, and Externalities", American Economic Review, June, 1969.

Our analysis, then, can make use of the following balance condition: Weight purchased - industrial waste = embodied weight. (2.9)

This means that it is necessary to make two adjustments to the inputs: (a) the effect of price must be eliminated so that purchases of inputs define weight of inputs; and (b) the amount of industrial waste must be subtracted.

Indirect Effects and the Inverse Matrix

A material may go through a number of stages before it is used and discarded. For example, to know the composition of scrapped automobiles, it is not sufficient to consider the purchases of metal by automobile firms; it is also necessary to consider the metal that has been purchased in order to produce the various components. To determine the composition of complex end products such as motor vehicles, it becomes necessary to accumulate the direct and indirect purchases of materials.

We have already seen that a term of the inverse matrix represents the direct and indirect production that is required because of final demand. For example, the inverse matrix tells us the production of steel that is required because of a unit purchase by motor vehicles. The inverse matrix can be thought of as "assigning" a material (such as steel) to various final demands (such as purchase of motor vehicles). Of course, it is necessary to adjust the inverse in a number of ways, e.g., to remove the effect of prices and to eliminate industrial waste. After appropriate adjustment, the inverse matrix will identify the amount of material required, per dollar, of each type of final expenditure. A prediction of the amount of consumer expenditure can then be translated into a prediction of the composition of embodied materials that will become solid waste when the purchased objects are discarded.

Non-Embodied Inputs

We have just seen that sequences of purchases in the input-output model, as represented by the inverse matrix, can be used to identify the material composition of end products. What is assumed is that a sequence of purchases represents the sequential refinement of materials that are finally embodied in final products. Such an assumption is not always a correct one. Consider the following sequence of industrial sales:

wood → lead mines → lead refining → automobile batteries → motor vehicles

This is a correct sequence for an input-output model because there is an exchange of money at each step. However, the wood used for shoring up lead mines does not become embodied in the motor vehicle. The lead ends up in the motor vehicle, but the inputs needed to mine the lead do not. Other examples can be given in which sequences in an input-output model do not represent the movement of materials in an economy:

fuel → steel → motor vehicles → households
repair parts → repair shops → households
tires → buses → households
steel → machine tool bits → motor vehicles → households.

In the first of these examples, fuel is consumed as used and is not passed on by the steel industry that uses it. In the second case, various kinds of repair parts do proceed to households, but they are exchanged for old parts in the repair shop; hence, the solid waste accumulates in the repair shop. In the third case, the rubber tires of the buses become solid waste at the bus depot, and are not carried to the home of the user of buses. Finally, in the case of machine tool bits, the material does not become incorporated in the object that is being produced.

All of these flows are legitimate elements of the input-output model, insofar as the model is concerned with sequences of inputs that are paid for. However, the sequences cited above cannot be included in the computation of household waste because they are not embodied physically in the final object.

These examples can be generalized so as to define three general categories in which the input-output model contains sequences that are not embodied.

(a) Inputs into raw materials (e.g., purchases by the mining or agriculture sectors).

(b) Service costs (e.g., transportation, repair, hotels, insurance).

(c) Overhead and manufacturing costs, including utilities (e.g., laboratory and office supplies, machine tool bits, fuels, electricity).

Purchases of these three kinds should be removed from the input-output model if it is to represent embodied flows.

Diagrammatically, the study of solid waste is concerned with the submatrix of embodied inputs. The input-output matrix can be partitioned as in Figure 2.3. We are interested in the summarizing that occurs in the inverse matrix, but our interest is in the inverse of the Embodied Submatrix: $(I - E)^{-1}$.

HOUSEHOLD, COMMERCIAL AND INDUSTRIAL WASTE

Industrial Process Waste

There are a number of reasons for considering the relationship between consumer expenditure and solid waste. One is to identify the extent to which consumer expenditure leads to the production of industrial process waste. Although it is outside the scope of this study, this is the traditional question posed in the input-output literature.* The relevant

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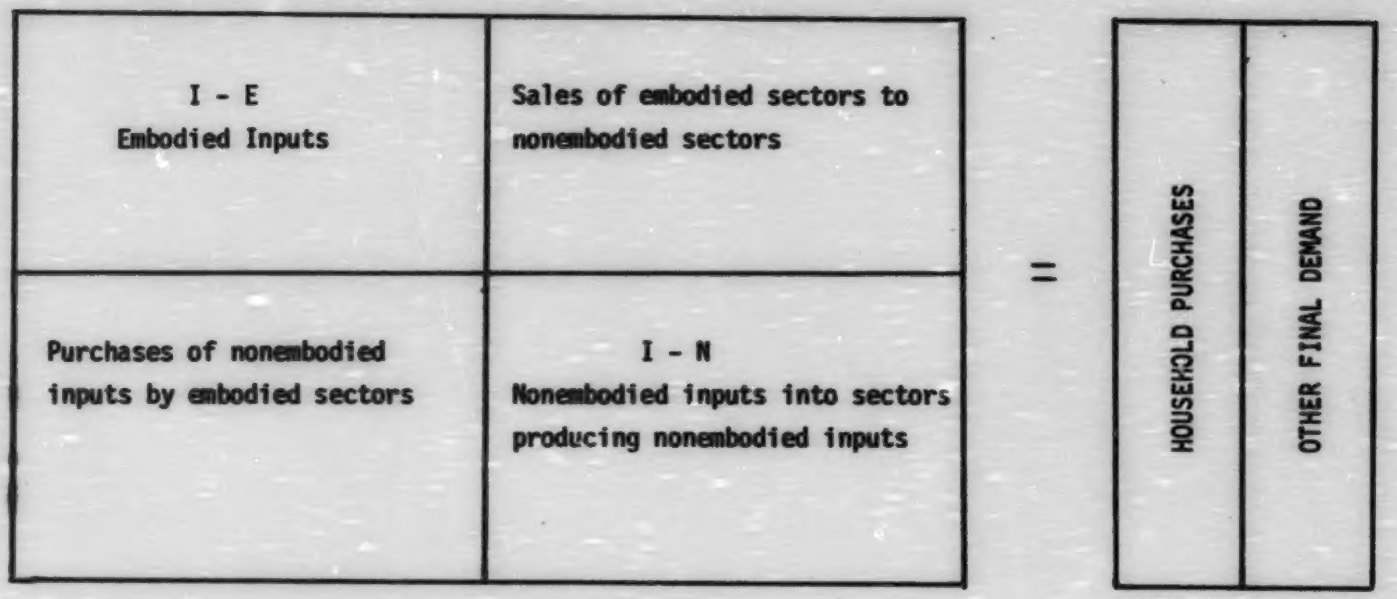
*Discussed in Appendix A

FIGURE 2.3

PARTITIONING OF THE INPUT-OUTPUT TABLE


I - E
Embodied Inputs
Sales of embodied sectors to nonembodied sectors
Purchases of nonembodied inputs by embodied sectors
I - N
Nonembodied inputs into sectors producing nonembodied inputs
=
HOUSEHOLD PURCHASES
OTHER FINAL DEMAND

equation would associate pollution coefficients with production levels as described in equation (2.6) above.

Waste Discarded by Households

The central issue to be explored in this study is the utility of input-output analysis in determining the amount and composition of municipal solid waste that results from personal consumption expenditure.

The input-output inverse, after appropriate correction, will generate a numerical profile of the materials used per end product. This profile, multiplied by the level of personal consumption expenditure will provide an estimate of household waste.

Commercial Waste

Municipal waste collection departments have an interest in the amount and composition of the total post-consumption waste to be collected by the municipal system, since this determines the costs of trucks and crews, and of the land upon which the waste is to be dumped. The composition of the waste may provide an opportunity for a city or contractor to plan to separate and sell certain fractions of the waste flows.

Municipal waste is collected not only from households, but also from other establishments such as office buildings, hotels, filling stations, grocery stores, etc. This type of waste is called commercial waste. The amount and composition of commercial waste can be determined by using an input-output model. The necessary steps are the following: First, define a set of industries that are commercial.* Second, define the proportion of each sector j that sells to the commercial sectors which is given in the input-output table. This proportion of sales is treated as if it were comparable to final demand; that is, it can be multiplied by the embodied inverse of an input-output model.

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*Appendix B, Table 1a has the list used in this study.

No list of commercial sectors is definitive. Different cities have different rules as to which types of waste are collected by municipal departments. In some, the municipal system collects from small factories such as those that finish leather. In other cities, office buildings and large apartments are required to remove their own waste. The categories that are relevant for the collection of waste are not necessarily identical with the categories used in the input-output model. For example, input-output tables do not separately identify restaurants, office buildings, or apartment buildings. A major research effort would be required to determine the best definition of commercial waste, and to relate this to the categories available in the input-output model. Such a research task was beyond the scope of this study. Further, this is not felt to be the most pressing research task that has been identified by this study. The preliminary list of commercial sectors used here is felt to be quite adequate for measurement of this kind of waste.

Recyclable Waste

Since every type of waste is a potential source for recycling, it is also desirable to identify the final use and disposal of all material that is produced. An input-output model is able to do this--it allocates production to all possible final uses. The following are the additional categories that can become the final repository of materials: construction, capital equipment, governments, exports, raw material producers (e.g., farms and mines). The Embodied Submatrix will allocate each material to these end uses as well as to households, commercial establishments and prompt industrial waste.

CHAPTER 3

METHODS FOR ADJUSTING AN INPUT-OUTPUT TABLE TO PROVIDE ESTIMATES OF SOLID WASTE

We have seen that the input-output table contains information that can be used to infer the amount and composition of post-consumer solid waste. The model does not provide a direct estimate, however, but requires that a number of adjustments be made. This chapter defines the methods of adjustment required.

THE APPROACH TAKEN BY THIS STUDY

In this report our approach will be iterative: we will first introduce a method that is easy to computerize, and will use it to provide preliminary estimates of the composition and quantity of household solid waste. This "method of minimal adjustment" makes several strong assumptions, so the next steps will be to identify the assumptions and to show how they can be tested. Finally, we will describe the kinds of adjustments which must be made when the assumptions are not valid.

An advantage of the method of minimal adjustment is that it makes efficient use of available data. The data in the input-output model is voluminous, complete, and readily computerized. When additional data is required, we generally find that it is incomplete and ill-structured. The task of reconciling categories, which is time-consuming and of questionable accuracy, can be confined to those cases where adjustment is found to be most necessary.

Some checking of the assumptions can be accomplished by internal analysis of the data in the input-output model. It will be possible to determine what occurs when the model is "solved", and then to identify the conditions that must be satisfied if the solution is to be accurate.

Our analysis will determine whether an input-output model can be used in the estimation of solid waste. It will identify which adjustments are most important and which could be ignored in the future. We will find that no type of adjustment can be ignored entirely, but that most types of adjustment are required for specific materials only.

This study also provides a critique of the input-output model. Thus, while some of the adjustments represent the special requirements of an analysis of solid waste, others represent inaccuracies of the available input-output models and should be made for any use of this model.

Economics is not a laboratory science in the sense that each analyst uses data obtained by him directly from nature. Most of the data used by economists has been processed and integrated by other analysts. It is important, in such a situation, that techniques be developed for criticizing the methods by which data is organized in economics. The present study provides a critique of some of the customs used in the collection of an input-output table. The criticism does not apply to the model as a mathematical system, but to the manner in which it is implemented empirically. The study identifies specific domains in which different procedures are desirable.

All input-output models of the United States economy make use of the bench-mark table that is provided by the Commerce Department. Since this input-output table is the basis of the Environmental Protection Agency's Strategic Environmental Assessment System (SEAS), which provides long-range projections of pollution levels, a critique of this table has consequences for EPA which extend considerably beyond the problems implicit in measuring the amount and composition of household solid waste.

THE METHOD OF MINIMAL ADJUSTMENT

The following steps are carried out:

1. Identify a set of industries which produce the materials that become solid waste.

2. Identify the tonnage of production of the materials for the year represented by the input-output table.
3. Adjust for industrial waste by subtracting it from the tonnage of production.
4. Identify a certain set of sectors that sell nonembodied inputs, and remove these sectors from the input-output table. The sectors that are left are called the Embodied Submatrix.
5. Compute the inverse of this Embodied Submatrix. This defines the amount of each material that is embodied in each type of final expenditure.
6. Multiply the inverse coefficients for each material by the level of final expenditure made by households and by commercial sectors.

Steps (1) and (4) require classifications of industries in the input-output table. The classification of materials is given in Table 3.1. The classification of nonembodied sectors and of commercial sectors is given in Appendix B, Table B-1a. Steps (2) and (3) which require data that is not available in the input-output table provide an adjusted weight of production. Steps (5) and (6) are computations that use data from the input-output tables. Steps (1), (4), (5), and (6) are easily programmed for a computer. The actual computational process, discussed below, will assist in identifying the assumptions implied by the use of this method. A mathematical statement of the minimal method is given in Appendix A.

THE ASSUMPTIONS OF THE METHOD OF MINIMAL ADJUSTMENT

a.) Time

In using data on industrial purchases to measure municipal waste, we assume an instantaneous transition from production to disposal. In so doing, we disregard any delays involving the steps of production, wholesaling, retailing and use before the object is disposed of. For some materials, e.g., most packaging materials, the time of use is short so the assumption introduces little difficulty. For other materials, the time

TABLE 3.1

THE MATERIALS THAT BECOME HOUSEHOLD SOLID WASTE

	Industry Number
Lumber & Wood Products	[41]
Paper & Paperboard Mills	[48]
Wall & Building Paper	[50]
Plastic Materials & Resins	[62]
Synthetic Rubber	[63]
Fibers*	
Leather Tanning & Industrial Leather Products	[75]
Glass	[78]
Pottery	[80]
Steel	[83]
Copper	[84]
Lead	[85]
Zinc	[86]
Aluminum	[87]
Primary Non-Ferrous Metals, NEC	[88]

*Fibers	
Wool	[3]
Cotton	[4]
Cellulosic Fibers	[64]
Non-cellulosic Fibers	[65]

of use is very long. The amounts of such materials discarded in a particular year may in fact be quite different from the amounts purchased Furthermore, the coefficients which relate household consumption to industrial production may change significantly over time. In such cases, the task of delineating dependencies in the economy is compounded with the task of forecasting future demand. The adjustments which must then be made are discussed in Chapter 5.

b.) Prices

Input-output tables can (in principle) be constructed in physical units, or they can be constructed in terms of values (price times quantity). If every term of the row is multiplied by the same price, then price does not matter, as shown in the following equation:

$$p_i\, t_{i1} + p_i\, t_{i2} + p_i\, t_{i3} + \dots + p_i\, f_i = p_i\, x_i \qquad (3.1)$$

The price, p_i, can be eliminated, giving equation (2.1). The minimal method says nothing about prices, but in assuming that inputs become embodied as weight in the final product, it assumes that inputs accurately represent weight of embodiment. Since available input-output tables measure the inputs in values, the implicit assumption is that each purchaser of a material pays the same price per pound. This assumption will be found to be very inaccurate, and will require substantial adjustment.

c.) Industrial Waste

The minimal method subtracts the waste that occurs during production from the weight of total production. Such an adjustment assumes implicitly that an identical proportion of scrap is lost during the process of manufacturing each end product. This assumption is tested and corrected when necessary.

d.) Independence of Materials

The analysis imputes the weight of end products by computing the weight of material that must be produced for them. If several materials are merely separate stages in the same sequence of flows (e.g., production of newspapers requires the production of paper and also of wood), then the end product will have several weights imputed to it. It is therefore necessary to eliminate those cases where one material becomes embodied in another material.

e.) Embodied Inputs

The objective of our analysis is to include inputs that are embodied but to exclude any inputs that are not. The minimal method achieves this objective by eliminating entire industries. However, some industries sell embodied inputs to some users and nonembodied inputs to other users. Such industries are included as part of the Embodied Submatrix, and the specific nonembodied sales are then removed one by one.

Some inputs have a more ambiguous status, insofar as they are changed in form during production. An example is wood chips which are altered when made into turpentine.

f.) Errors in the Input-Output Model

An implicit assumption of the analysis is that computations of coefficients in an input-output model will accurately represent flows of materials. This is noticeably not the case if the input-output model contains aggregation errors. Conditions for the avoidance of such errors, which distort the estimations of final waste and which do not fully account for the way in which it would be recycled, are described later in this chapter.

The remainder of this chapter discusses how to determine whether these assumptions are inaccurate and how to make the required adjustment when they are. The assumption concerning time, however, is relegated to Chapter 5, which considers dynamic aspects of the analysis.

ADJUSTMENT FOR PRICES AND INDUSTRIAL WASTE

It has been pointed out that the minimal method assumes implicitly that every user of a material pays the same price. If each user pays a different average price for a material, then equation (3.1) would have to be changed to

$$p_{i1}\ t_{i1} + p_{i2}\ t_{i2} + p_{i3}\ t_{i3} + \ldots + p_{if}\ f_i = p_i\ x_i \qquad (3.2)$$

Each transaction in the input-output table would have to be adjusted by

$$\frac{p_i}{p_{ij}} \quad \text{or} \quad \frac{p_i}{p_{if}}$$

if the transactions are to represent physical weight.

The assumption for industrial waste is that each end product has lost the same proportion of waste by the time it reaches the final user. A more accurate assumption would use a waste ratio w_{ij}, which is a proportion of the purchases t_{ij}. The embodied quantity would therefore be defined as

$$e_{ij} = t_{ij} - w_{ij}\ t_{ij} = (1 - w_{ij})\ t_{ij} \qquad (3.3)$$

e_{ij} is the quantity of material i embodied at production of j

t_{ij} is the purchase of material i by producer j

w_{ij} is the proportion of the material that becomes prompt industrial waste.

A further complexity is that waste can occur at each step of production. For example, steel waste will occur when a piston ring is produced, some piston rings will be found to be faulty when inspected, and some will be damaged as they are installed.*

The general ratio is

$$a_{ij}\ a_{jk}\ a_{km}\ (1 - w_{ij})\ (1 - w_{ijk})\ (1 - w_{ikm}) \qquad (3.4)$$

where w_{ikm} is the proportion of scrap of material m used by sector n that contains material i.

---

*The loss rate of piston rings is given as 20% in Table 4.3 in Ayres, Robert U., and Noble, Stedman B., "Economic Impact of Mass Production of Alternative Low Emissions Automotive Power Systems", Report #DOT-OS-20003 (Amended), prepared for Department of Transportation, March 6, 1973.

It is not necessary to adjust for prices at a later stage of producing. Pricing of complex assemblies is an aspect of the problem of aggregation and is best analyzed when considering the possibility of aggregation errors.

TESTING THE OTHER ASSUMPTIONS

To test the assumptions concerning price and industrial waste, it is necessary to obtain data beyond that which is contained in the input-output table. For the remaining assumptions, the input-output data is sufficient. In each case, however, it is necessary to interpret the meaning of this data, and this requires the use of information that is not provided by the input-output table.

The assumption concerning the independence of materials can be tested by determining whether industries sell to one another. The relevant sales may involve a number of steps, e.g.,

lumber → wood products → paper.

For each case, it is necessary to determine whether the material i sold to material j is introduced before or after material j is weighed. In the following case,

zinc → steel

the zinc is used to galvanize steel and this operation occurs after the weight of steel is defined. Therefore, this input of zinc is added to the weight of the steel and does not involve double-counting of weight. These examples illustrate the hypothesis that when there is double-counting of weight, additional information is required to determine whether the hypothesis is accurate.

In the identification of inputs that are not embodied, the input-output model again provides the possible candidates, and information beyond the model is required to determine whether a specific input is or is not embodied. Some examples illustrate:

lumber → steel → motor vehicles
rubber → rubber products → printing → households

Each of these sequences appears to involve inputs that represent maintenance costs rather than embodied inputs.

The input-output model can be used to identify cases where the final forms of disposable objects are misstated. Two examples illustrate:

lumber ⟶ furniture ⟶ house trailers
lead ⟶ batteries ⟶ motor vehicles

In each case, the material in question would be thrown out or recycled directly. Furniture would not be left in a house trailer to be demolished; nor would a battery normally be left in an automobile that is to be shredded.

Finally, the input-output model can produce errors because of excessive aggregation of industries. It is essential to test the adequacy of aggregations in the model, and to adjust for any cases in which the classification results in material flows that are wrong. This adjustment has proved to be a major operation in the present study (as will be seen below and in Chapter 4), insofar as a number of cases exist in which the composition of output from a given sector varies widely depending on the nature of the subsequent use.

This adjustment can be made by comparing the structural dependence as defined by the input-output model with the structural dependence known to occur in the economy. It will be possible to see how the input-output model computes structural dependence and to identify the assumptions that must be satisfied if the method of computation is to be accurate. An advantage of this approach is that it will identify how to carry out sensitivity analysis in the input-output model.

COMPUTATION OF PATH PRODUCTS

Chapter 2 points out that the system of equations can be solved by computing an inverse matrix. The inverse represents direct and indirect effect, i.e., all of the reasons for producing steel because of the demand for a motor vehicle. Steel is purchased directly by motor vehicle firms, which also purchase components made of steel. Other purchases may require the indirect production of steel. The inverse term can be obtained by computing all of these effects and adding them.

An example will illustrate how indirect effects are computed. Table 3.2 gives the major sales of glass. Sales of glass to final demand (e.g., windows) and to nine industries account for 75% of the sector's output. Table 3.3 shows the sales of these nine industries, along with several others. The coefficients in these tables are the proportions of output, which in each case add to unity.

Our interest is in the indirect impacts that are defined by the inverse matrix. Therefore, it is necessary to combine the two tables into a single table showing indirect impacts. For example, the glass industry sells to the soft drinks industry, and soft drinks are purchased by households; therefore, glass bottles for soft drinks are disposed of by households. To determine a quantitative relationship, the numbers are multiplied:

Glass to Soft Drinks	.13	Table 3.2
Soft Drinks to Households	.92	Table 3.3
Glass to Soft Drinks to Households	.13 x .92 = .12	

Indirect effects are obtained by multiplying the coefficients.

Any sequence of flows of this type will be called a path, and the product will be called a path product. Every sale of glass (Table 3.2) is multiplied by the coefficients at the next step (given in Table 3.3). Three types of path products can be obtained:

1. i → j → Final Demand of j
2. i → j → k
3. i → j → Other

The first is a completed path product. The second is a path product in process, and the third is a path product that must be discontinued. All such paths originating from glass are given in Table 3.4.

As long as there are paths in process, the paths can be extended further. The extension is shown in Table 3.5, in which no paths remain in process. Some paths proceed four steps before they reach final demand or reach "other".

To summarize, the general method is the following:

(a) List the sales of every industry in the economy. This is done in an input-output table.

TABLE 3.2

LARGEST SALES OF SECTOR 78 (GLASS)

FRACTION OF GLASS SALES	PURCHASING SECTOR
.13	Final Demand
.04	Maintenance and Repair Construction [19]
.09	Canned & Frozen Foods [25]
.11	Alcoholic Beverages [30]
.13	Soft Drinks & Flavorings [31]
.03	Misc. Food Products [33]
.03	Cleaning & Toilet Preparations [67]
.03	Electric Lighting and Wiring Equipment [124]
.05	Electronic Components [128]
.11	Motor Vehicles and Parts [133]
.25	Other
1.00	TOTAL

TABLE 3.3

SALES OF MAJOR GLASS CONSUMERS

Industry and Sector	Fraction of Sales by Major Glass Consumers	Purchasing Sector	Name
Maintenance and Repair Construction [19]	.26 .20 .20 .34 1.00	Final Demand 167 168 Other	Owner-Occupied Dwellings Other Real Estate
Canned and Frozen Foods [25]	.96 .04 1.00	Final Demand Other	
Alcoholic Beverages [30]	.86 .14 1.00	Final Demand Other	
Soft Drinks & Flavorings [31]	.92 .08 1.00	Final Demand Other	
Miscellaneous Food Products [33]	.91 .09 1.00	Final Demand Other	
Cleaning & Toilet Preparations [67]	.77 .06 .04 .13 1.00	Final Demand 170 171 Other	Personal & Repair Services Business Services
Electric Lighting & Wiring Equipment [12	.68 .07 .06 .19 1.00	Final Demand 19 133 Other	Maintenance & Repair Construction Motor Vehicles & Parts
Radio & TV Receiving [125]	.91 .09 1.00	Final Demand Other	

TABLE 3.3 (Con't)

Industry and Sector	Fraction of Sales by Major Glass Consumers	Purchasing Sector	Name
Communications Equipment [127]	.86	Final Demand	
	.14	Other	
	1.00		
Electronic Components [128]	.17	Final Demand	
	.25	125	Radio and TV Receiving.
	.26	127	Communications Equipment
	.12	170	Personal and Repair Services
	.20	Other	
	1.00		
Motor Vehicles & Parts [133]	.93	Final Demand	
	.07	Other	
	1.00		
Aircraft [134]	1.00	Final Demand	
Owner-Occupied Dwellings [167]	1.00	Final Demand	
Other Real Estate [168]	.41	Final Demand	
	.59	Other	
	1.00		
Personal and Repair Services [170]	.88	Final Demand	
	.12	Other	
	1.00		
Business Services [171]	.37	Final Demand	
	.63	Other	
	1.00		
Auto Repair [173]	.66	Final Demand	
	.34	Other	
	1.00		

TABLE 3.4

TWO-STEP PATHS AND PRODUCTS FOR SECTOR 78 (GLASS)

1 PATH PRODUCT	2 COMPLETED PATH PRODUCT	3 PATH PRODUCT IN PROCESS	4 NOT IDENTIFIED	PATHS Step 1	 Step 2
.13	.13			78 Final Demand	
.04	.04 x .26			78 19 Maintenance & Repair Construction	Final Demand
.04 x .20		.04 x .20		78 19	167 Owner-Occupied Dwellings
.04 x .20		.04 x .20		78 19	168 Other Real Estate
			.04 x .34	78 19	Other
.09	.09 x .96			78 25 Canned & Frozen Foods	Final Demand
			.09 x .04	78 25	Other
.11	.11 x .86			78 30 Alcoholic Beverages	Final Demand
			.11 x .14	78 30	Other
.13	.13 x .92			78 31 Soft Drinks & Flavorings	Final Demand
			.13 x .08	78 31	Other
.03	.03 x .91			78 33 Misc. Food Products	Final Demand
			.03 x .09	78 33	Other
.03	.03 x .77			78 67 Cleaning & Toilet Preparations	Final Demand
.03 x .06		.03 x .06		78 67	170 Personal & Repair Services
.03 x .04		.03 x .04		78 67	171 Business Services
			.03 x .13	78 67	Other
.03	.03 x .68			78 124 Electric Lighting & Wiring Equipment	Final Demand
.03 x .07		.03 x .07		78 124	19 Maintenance & Repair Construction
.03 x .06		.03 x .06		78 124	133 Motor Vehicles & Parts
			.03 x .19	78 124	Other
.05	.05 x 17			78 128 Electronic Components	Final Demand
.03 x .25		.03 x .25		78 128	125 Radio & TV Receving
.03 x .26		.03 x .26		78 128	127 Communications Equipment
.03 x .12		.03 x .12		78 128	170 Personal & Repair Services
			.03 x .20	78 128	Other
.11	.11 x .93			78 133 Motor Vehicles & Parts	Final Demand
			.11 x .07	78 133	Other
			.25	78 Other	

TABLE 3.5
MAJOR PATH PRODUCTS FOR SECTOR 78 (GLASS)

1	2	3	4	PATHS				
PATH PRODUCT	COMPLETED PATH PRODUCT	PATH PRODUCT IN PROCESS	NOT IDENTIFIED	Step 1		Step 2		
.13	.13			78	Final Demand			
.04	.04 x .26			78	19 Maintenance Construction	Final Demand		
.04 x .20	.04 x .20 x 1.00			78	19	167 Dwellings	Final Demand	
.04 x .20	.04 x .20 x .41			78	19	168 Other Real Estate	Final Demand	
			.04 x .20 x .59	78	19	168	Other	
			.04 x .34	76	19	Other		
.09	.09 x .96			78	25 Canned, Frozen Foods	Final Demand		
			.09 x .04	78	25	Other		
.11	.11 x .86			78	30 Alcoholic Beverages	Final Demand		
			.11 x .14	78	30	Other		
				78	31 Soft Drinks	Final Demand		
				78	31	Other		
.03	.03 x .91			78	33 Misc. Food Products	Final Demand		
			.03 x .09	78	33	Other		
.03	.03 x .77			78	67 Cleaning, Toilet Preparations	Final Demand		
.03 x .06	.03 x .06 x .88			78	67	170 Personal, Repair Services	Final Demand	
			.03 x .06 x .12	78	67	170	Other	
.03 x .04	.03 x .04 x .37			78	67	171 Business Services	Final Demand	
			.03 x .04 x .63	78	67	171	Other	
			.03 x .13	78	67	Other		
.03	.03 x .68			78	124 Electric Lighting Equip.	Final Demand		
.03 x .07	.03 x .07 x .26			78	124	19 Maintenance Construction	Final Demand	
.03 x .07 x .20	.03 x .07 x .20 x 1.00			78	124	19	167 Dwellings	Final Demand
.03 x .07 x .20	.03 x .07 x .20 x .41			78	124	19	168 Other Real Estate	Final Demand
			.03 x .07 x .20 x .59	78	124	19	168	Other
.03 x .06	.03 x .06 x .93			78	124	133 Motor Vehicles	Final Demand	
			.03 x .06 x .07	78	124	133	Other	
			.03 x .19	78	124	Other		
.05	.05 x .17			78	128 Electronic Components	Final Demand		
.05 x .25	.05 x .25 x .91			78	128	125 Radio & TV Receivers	Final Demand	
			.05 x .25 x .09	78	128	125	Other	
.05 x .26	.05 x .26 x .86			78	128	127 Communication Equip.	Final Demand	
			.05 x .26 x .14	78	128	127	Other	
.05 x .12	.05 x .12 x .88			78	128	170 Personal, Repair Services	Final Demand	
			.05 x .12 x .12	78	128	170	Other	
			.05 x .20	78	128	Other		
.11	.11 x .93			78	133 Motor Vehicles	Final Demand		
			.11 x .07	78	133	Other		
.25			.25	78	Other			

(b) Starting with a sector i (e.g., glass), identify new sectors by tracing the sales of this sector to major purchases.

(c) Prorate the sales by multiplying outputs, to yield the following:

$$\begin{array}{ll} h_j & \\ o_{ij} \times h_j & \text{for all } j \\ o_{ij} \times o_{ij} & \text{for all } j \end{array} \qquad (3.5)$$

h_j is the proportion of output of sector i going to households; o_{ij} is the proportion of output of sector i going to sector j.*

(d) Continue to follow the sales of any sectors that have been reached: $i \rightarrow j \rightarrow k \rightarrow l \rightarrow m$ etc.

(e) Continue to prorate. Hence:

$$\begin{array}{ll} h_j & \\ o_{ij} \times h_j & \text{for all } j \\ o_{ij} \times o_{jk} \times h_k & \text{for all } j \text{ and } k \\ o_{ij} \times o_{jk} \times o_{kl} \times h_l & \text{for all } j, k, \text{ and } l \\ o_{ij} \times o_{jk} \times o_{kl} \times o_{lm} \times h_m & \text{for all } j, k, l, m. \end{array} \qquad (3.6)$$

If a portion of the sales of sector m goes to other sectors, the process can continue. It stops whenever final demand is reached.

Any term of the inverse matrix equals the sum of all path products starting with sector i and ending with sector m.

The computation does for this study differs from the example in the following ways:

(1) The data is more complete than that given in Tables 3.2 and 3.3. No category "other" is used.

(2) Path products that are small are not computed. Truncation is based upon a threshold of .0002. Every path product accounting for more than this proportion of output is computed.

(3) Columns (3) and (4) of Tables 3.4 and 3.5 are omitted. The lines ending in "other" are omitted.

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*See Appendix A for the relationship between input and output coefficients.

(4) The path products are sorted in three different ways, as shown in Appendix C.

(5) A new third column is provided that gives the cumulative sum of the quantities that have reached final demand given in Column (2).

Path Products and Sensitivity Analysis

The inverse matrix defines structural dependence. An inverse term,

$$b_{ik} = 0.15,$$

shows that a unit of final demand for k requires 0.15 units of production of i. The inverse matrix, then, gives a direct measure of the sensitivity of any industry to changes in final demand.

The path products provide two types of additional information about the structural dependence in the model. The path identifies the sequence of steps of a commodity, or of monetary transactions. The product of the path identifies the significance of the path for the industry at its origin. To illustrate,

$$o_{ij} \times o_{jk} \times h_k = 0.10$$

shows that 10% of the output of i depends upon household expenditure for k. The inverse term ik is the sum of all path products that begin with i and end with k. Therefore the same sensitivity applies to each path product. This sensitivity defines the impact upon i of a change in purchases of k resulting from the path

$$i \rightarrow j \rightarrow k \rightarrow h_k$$

The new information given by the path is that the term jk is involved. The inverse matrix does not tell us where each of the inverse terms comes from--i.e., the sequences that are involved.

Path products can be used to determine the effect of a change in coefficients upon the answers of the model. Suppose that the input coefficient a_{jk} were to decrease by 20 percent. This would mean that the amount of j (e.g., stampings) required per unit of k (e.g., motor vehicles) would also be reduced 20 percent. In this case, the output of i would be reduced 2 percent as given by

$$0.10 \times 0.20 = 0.02.$$

All paths containing o_{jk} would similarly be reduced by 20 percent.

Path products, then, define the sensitivity of the answer to changes in coefficients. Moreover, path products can be revised when available information indicates that they are inaccurate. It may appear surprising that a system of simultaneous equations can be adjusted this easily: i.e. that path products can so easily show the sensitivity of the model to changes in coefficients. In fact, not all systems of simultaneous equations can be adjusted so readily. The facility of adjustment depends upon the extent to which a complete set of path products can be computed. If the inverse can be fully represented by path products, then the effect of a change in coefficients can be fully handled by making changes in all relevant path products. To the extent that the set of path products is incomplete, then a part of the interdependence cannot be handled in such a direct manner. The number of path products which can be computed, therefore, must be empirically investigated. Before that investigation can be made, it is necessary to make some further observations about the process by which path products are formed.

Validity of Multiplication

Path products are formed by multiplication, and it is possible to test whether multiplication is an appropriate operation. Consider two inputs a_{SM} and a_{AM} into sector M. In forming path products, each input is multiplied by the coefficients representing sales by M:

$$a_{SM} \times a_{Mk} \quad \text{and } a_{AM} \times a_{Mk} \quad \text{for all k.}$$

Thus, the two inputs are assumed to be used in the same proportion. The assumption of proportionality can be tested whenever data is available to define whether the different sales by M make use of specific inputs S or A. Figure 3.1 is a case in which the relevant information is available. It shows the inputs of aluminum and tin-plated steel into "tin" cans. It also shows the major uses of metal cans. The assumption of multiplication can be viewed in two ways. On one hand, it may be assumed that the uses of each metal would be proportional to the uses of metal cans, and on the other hand it may be assumed that each user is using the same ratio of steel and aluminum in his cans.

Table 3.6 compares the assumption with the actual situation. Department of Commerce data shows that aluminum is used in substantial quantities for meat, beer, soft drinks, and "other foods", but almost not at all used for fruit juices, evaporated milk, fish and many other products. Table 3.6 shows the 1971 proportions of steel and aluminum for these four categories. The proportion of aluminum cans used for meat and beer is much larger than that used for soft drinks and other foods. Clearly the assumption of prorating is incorrect in this case, and should be adjusted to fit the actual data.

It is important to distinguish, at this point, between predictive accuracy and structural accuracy. Table 3.6 shows that the input-output model has structural errors; that it does not correctly state what would happen to the demand for different inputs if people purchased more beer and less canned food. A model can have structural errors and can predict accurately to the extent that final purchases continue to occur in the same proportion. In the example just cited, if consumer purchases of beer and canned food remain in fixed proportions over time (and if the change in coefficients with time is correctly predicted), then the model will predict accurately. Our purpose, however, is not so much to predict as to delineate the structural interdependence of various kinds of economic activity. We are interested in using the input-output model to provide answers for contingencies and these answers prominently include different patterns of end-use consumption. For this broader purpose,

FIGURE 3.1

SOME INPUTS AND USES OF METAL CANS

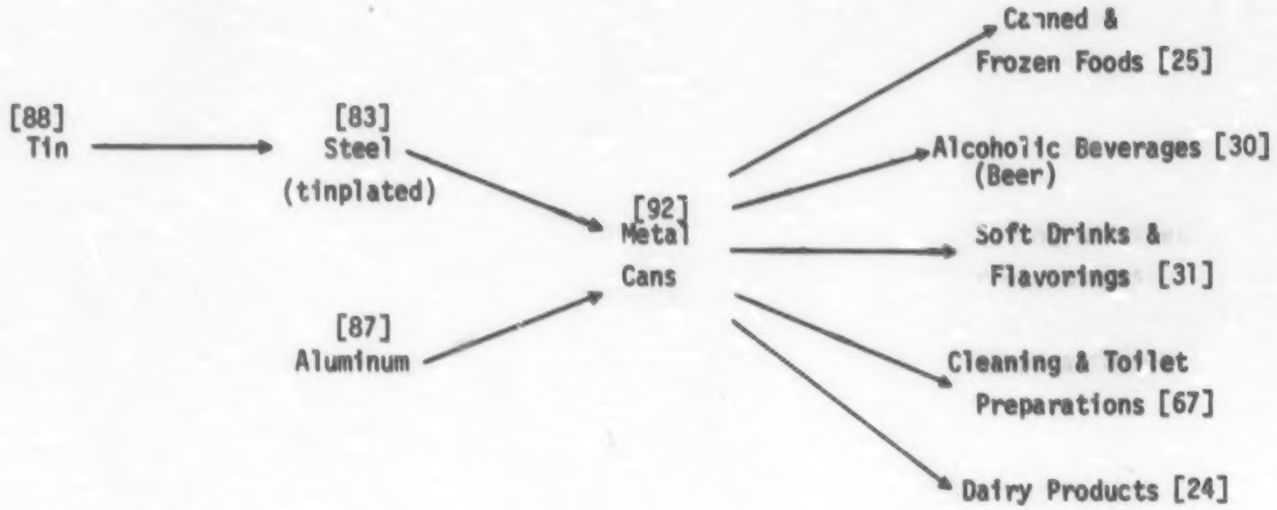

[88]
Tin
[83]
Steel
(tinplated)
[87]
Aluminum
[92]
Metal
Cans
Canned &
Frozen Foods [25]
Alcoholic Beverages [30]
(Beer)
Soft Drinks &
Flavorings [31]
Cleaning & Toilet
Preparations [67]
Dairy Products [24]

TABLE 3.6

PRORATED AND ACTUAL USES OF METALS IN CANS

	Prorated*		Actual**		
Industry and Sector	Steel	Aluminum	Steel	Aluminum	
Canned & Frozen Foods[25]	.9809	.0191	.9847	.0153	
Alcoholic Beverages[30] (Beer)	.9809	.0191	.7891	.2109	s
Soft Drinks[31]	.9809	.0191	.8925	.1075	s
Dairy Products[24]	.9809	.0191	.9915	.0085	
Meat Products[23]	.9809	.0191	.8626	.1374	s
Miscellaneous Food[33] Products	.9809	.0191	1.0000	--	
Paint[68]	.9809	.0191	1.0000	--	
Other Non-Food	.9809	.0191	.9883	.0117	

*Assessment in the input-output model.

**Given in Containers and Packaging, April, 1974

s For the items marked "s", the differences are regarded as significant.

the input-output model is inaccurate in its allocations of metals to uses of metal cans. Therefore, the model needs to be revised, even if it has been predicting accurately.

It will not be possible to find the data required to check every case in which prorating is done. That would require an extensive program of searching for data and making estimates where data are unavailable. It is possible, however, to identify the conditions under which errors could occur or would never occur. The assumption of a matrix is that the various inputs of an industry are complements which will be (must be) used in a fixed proportion. This assumption is most questionable for materials that can replace one another, such as aluminum and steel in metal cans. The assumption is approximately valid for steel and copper in motor vehicles, since they have different functions; copper is used for radiator tubing and most other metallic parts are of steel.

A number of situations can be defined wherein the assumption of multiplication is valid.

(1) Necessity of input. An input is necessary if it must be used in the same proportion in every type of output of the industry. One necessary condition for this to be satisfied is that there be no input that could substitute in place of the input.

(2) Sole use. The multiplication assumption is also valid when the entire output of an industry flows to a single use. "Sole use" is most apt to occur for finished materials that are sold solely to households. For example, radio and T.V. receivers (Industry 125) are sold almost entirely to consumer households, so whatever is purchased to produce them will--if it is an embodied input--end up as household waste. The question of proportionality ceases to be necessary in such a case.

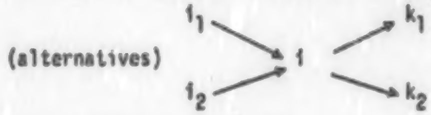
Figure 3.2 provides a diagrammatic analysis of the reasons for error and the situations in which error is avoided. This figure generalizes the cases to longer paths. In particular, the situation

i is necessary for all sales from j (N)
j sells to k
k sells solely to m (S)

FIGURE 3.2

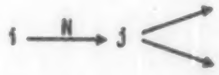
A GENERAL DESCRIPTION OF CASES IN WHICH PRORATING ERRORS WOULD NOT OCCUR

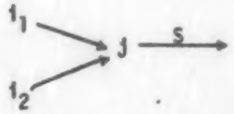
There can be an error whenever alternative inputs go to joint sales:


(alternatives)
i_1
i_2
i
k_1
k_2

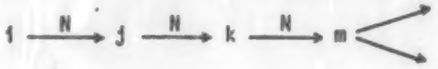
since all of i_1 could go to k_1 or k_2.

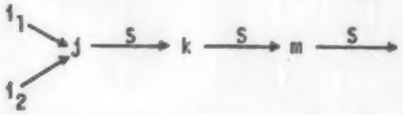
It is possible to define cases where no prorating error would occur:



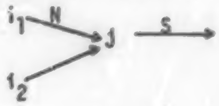


Longer flows can involve repetition of each of these:

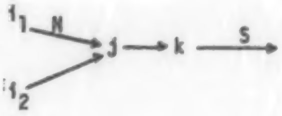



i_1
i_2
j
S
k
S
m
S

Combining them, the sequence:

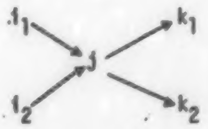


is valid for i_1 and i_2,



is valid for i_1 and i_2.

$i \xrightarrow{S} j \xrightarrow{N} k$ need not be valid since it is equivalent to



$i \xrightarrow{N} j$ means that i is necessary for every product sold by j.

$j \xrightarrow{S} k$ means that j sells solely to k.

means that for the sequence

$$i \xrightarrow{N} j \longrightarrow k \xrightarrow{S} m$$

the assumption of proportionality is valid.

The next chapter will show that many materials satisfy the conditions necessary for an input-output model to provide valid allocations of household waste. There are some materials, however, for which few of the paths satisfy the criteria given here and for which the results of the input-output model cannot be accepted.

How to Avoid Prorating Errors

The input-output model avoids prorating errors in its treatment of wholesale and retail trade. The procedure used here serves as a guide to the avoidance of prorating errors generally.

A sequence of monetary flows would handle trade in the following manner:

Manufacturer of finished product → Wholesaler of the product → Retailer of the product → Household

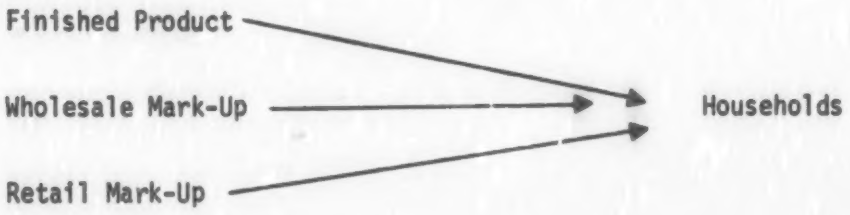
Now the model faces a dilemma. If it describes most products as being sold to one wholesale industry and one retail industry, then most consumer expenditure would be from a single industry, and the level of production would be dominated by the proportions of inputs into this industry in general--but not into its components. For example, the model would no longer tell us the effect on the economy due to a reduction in demand for house trailers which might be accompanied by an increased demand for textbooks. The other option would be for the model to disaggregate the wholesale and retail trade sectors so that there was a separate one for every finished commodity. This would increase intolerably the number of sectors in the table.

Both difficulties are avoided by treating wholesale and retail trade as a service. The wholesale and retail sectors purchase heat, light, paper bags, ets., but they do not produce the commodities for resale. Their income is the mark-up, not the total price of the objects that they sell.

This is shown diagrammatically by Figure 3.3. The model requires a figure for the total wholesale trade and retail trade activity that is associated with consumer expenditures.

FIGURE 3.3

TREATMENT OF TRADE MARGINS IN INPUT-OUTPUT MODELS



A similar approach could be used in an analysis of metal cans. It is possible to ignore the purchase of metal by metal cans and to allocate the steel and aluminum directly to the industries that purchase metal cans. This involves a correction of a path product that involves two steps, Steel (or Aluminum) to Metal Cans to Soft Drinks. The metal can industry continues to account for the operation of fabricating metal cans, but its inputs of metals are superseded.

Since this adjustment requires data of the kind given in Table 3.6, and since such data are not generally available, our analysis will confine itself to identifying the cases where prorating errors may occur and the extent of uncertainty that results. Chapter 4 will show that even when we eliminate all cases where prorating errors may occur, the input-output model provides a very large amount of detailed information on the composition of household solid waste.

The Completeness of Path Products

It was not possible, in this study, to compute all possible path products. In fact, it can be shown that some path products exist that are infinitely long and whose value approaches zero.* Clearly it was necessary to confine the computations in some way. A threshold was introduced and no path was computed that accounted for less than .0002 of the output of its originating sector.

Under this limitation, almost 1,700 distinct paths were computed for the 17 materials being analyzed. However, about 75% of the output was accounted for by only 214 of these paths. Table 3.7 shows the number of paths required to account for 75% of the output of each material, versus the total number of paths which can be identified assuming thresholds of different sizes (.0002 and .0005). This table shows that the smaller paths add much bulk to the analysis while contributing relatively little information.

An economy, then, appears to consist of a small number of major dependencies and a very large number of distant effects. Chapter 4 will show the proportion of output that is represented by path products and will evaluate the significance (for this approach to waste estimation) of the fact that the list of path products analyzed is necessarily incomplete.

Now let us consider how to determine the amount of sales that is lost by truncation of path products. Recall that path products begin with sales as shown in Table 3.2 which sum to 1.0. Figure 3.4 illustrates the next step; a term is multiplied by a set of terms that add to 1.0. By multiplication of the path products we produce the following set:

---

*This will be the case whenever there is a cycle--a path that begins and ends with the same sector. To illustrate, the path $i \rightarrow j \rightarrow i$ (which is a cycle) involves an infinite number of paths: $i \rightarrow j \rightarrow i \rightarrow j \rightarrow i \rightarrow$ etc.

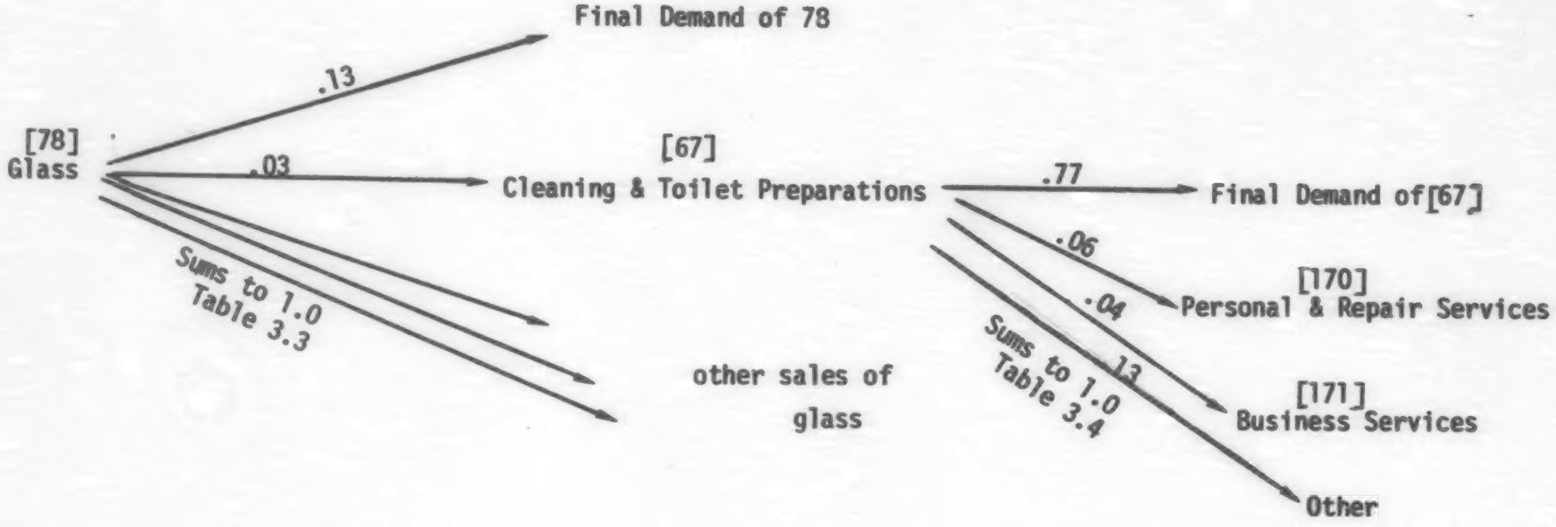
TABLE 3.7

THE NUMBER OF PATH PRODUCTS BY MATERIAL FOR VARIOUS THRESHOLDS

Material and Sector	Number of Paths			
	75% Accounted	Threshold		Difference in Coverage between .0005 and .0002
		.0005	.0002	
Cotton [4]	6	38	64	.008
Lumber [41]	5	23	40	.005
Paper & Paperboard Mills [48]	14	82	125	.014
Building Paper Mills [50]	7	19	37	.005
Plastic Materials & Resins [62]	35	96	180	.025
Synthetic Rubber [63]	4	38	75	.011
Cellulosic Fibers [64]	8	71	113	.013
Non-Cellulosic Fibers [65]	8	63	99	.012
Leather Tanning & Industrial Leather Goods [75]	2	14	22	.003
Glass [78]	5	39	65	.008
Pottery [80]	1	16	27	.003
Steel [83]	13	58	92	.011
Copper [84]	21	48	78	.009
Lead [85]	20	84	177	.029
Zinc [86]	35	99	209	.034
Aluminum [87]	18	57	103	.015
Other Primary Non-Ferrous Metals [88]	12	97	192	.028
TOTAL	214	942	1,698	

FIGURE 3.4

PRORATED OUTPUT OF GLASS BY SECTOR 67


[78]
Glass
.13
Final Demand of 78
.03
[67]
Cleaning & Toilet Preparations
Sums to 1.0
Table 3.3
other sales of
glass
.77
Final Demand of [67]
.06
[170]
Personal & Repair Services
.04
[171]
Business Services
.13
Sums to 1.0
Table 3.4
Other

.03 x .77	78 to 67 to final demand of 67
.03 x .06	78 to 67 to 170
.03 x .04	78 to 67 to 171
.03 x .13	78 to 67 to other sales of 67.
.03 x 1.00	

Since the outputs of 67 sum to 1.00, the path products from 78 to 67 will continue to sum to .03. That is, extending the path products an additional step does not change the proportion of output that is represented.

The same result will occur at each step. Extending the path product will retain the same proportion of output. Since path products can be extended until they are completed (reach final demand), the sum of all completed path products will sum to 1.0 when no path products are eliminated. Two consequences follow: (1) after introduction of a threshold, the sum of all path products that are computed will be 1.0 or less, and the amount less than 1.0 will identify the proportion of sales lost because of truncation; and (2) the locale of the loss can be identified by comparing the materials inputs and outputs of individual sectors. Illustrated in Table 3.8 is the sales of glass to Sector 124 (electric lighting and wiring equipment) and Sector 128 (electronic components). In one case, 25% of the input is truncated, and in the other case, truncation represents 17%.

TABLE 3.8

PATH PRODUCTS FOR SECTOR 78 (GLASS)

Fraction of Sales to Major Glass Consumers	Completed Path Product	Not Identified		
To Electric Lighting & Wiring Equipment (124)				
.038356	.023577		78 124	Final Demand
	.001177		78 124 19	Maintenance Construction
	.001055		78 124 114	Computers & Related Equipment
	.000604		78 124 127	Communications Equipment
	.002295		78 124 133	Motor Vehicles & Parts
	.028708	.009648 (25%)		
To Electronic Components (128)				
.047721	.008141		78 128	Final Demand
	.000891		78 128 20	Complete Guided Missiles & Space Vehicles
	.002604		78 128 114	Computers & Related Machines
	.000999		78 128 118	Electrical Measuring Instruments
	.011113		78 128 125	Radio & T.V. Receiving
	.011426		78 128 127	Communications Equipment
	.000830		78 128 127	134
	.000502		78 128 141	Engineering & Scientific Instruments
	.003072		78 128 170	Personal & Repair Services
	.039578	.008143 (17%)		

CHAPTER 4

RESULTS FOR THE BASE YEAR

This chapter provides empirical findings on the quantity and composition of household waste, as obtained from an input-output table for a base year (1971). Chapter 5 provides forecasts for future years.

It is appropriate to review briefly the method taken by the study so as to identify the particular kinds of empirical evidence required. Beginning with the total weight of production, the input-output model defines the proportion of this weight that goes to various ends uses from which it is eventually discarded as waste. The input-output model allocates by type of user (e.g., consumer households, commercial users, industrial users, construction activity) -- and by the form of the end use (e.g., packaging, motor vehicles, refrigerators, shoes).

Two broad empirical problems are encountered. First, it is necessary to identify the weight of any production that can become embodied in final products. Second, it is necessary to determine whether the input-output model does the required task of allocating this weight to the end uses that become household waste. For the latter task, this chapter analyzes each of the possible types of error in the input-output model described in the previous chapter, corrects as many errors as possible, and identifies the extent to which the results of the model are uncertain. This chapter thereby provides a critique of the input-output model that was used in the analysis.

THE PHYSICAL WEIGHT OF PRODUCTION

Since a material generally proceeds through a number of processing steps, such as extraction, purification, and combination into finished objects, its weight can be measured at a number of points. It is sufficient to measure this weight only once. There are two criteria for selecting the measurement point: (1) to simplify the adjustment for waste, and (2) to obtain as much information as possible. Some examples illustrate these criteria. The weight of steel incorporated into a motor vehicle is a better indication of the scrap than is the weight of the iron ore produced for the same vehicle. The implication is that weight should be measured at a late stage in the processing chain. On the other hand, there are other materials for which measurement may be more desirable at an early stage. For example, different types of fiber have quite different heat content, so an analysis that considers the combustion value of discarded textiles would require information on weight by _type_ of fiber, rather than merely for textiles in general. Considerations of this kind have led us to the conclusion that the best point for measuring weight is the last stage _at which the material is uncombined with other materials_.

Since the input-output model will be used to allocate materials to end products, the weight of materials must be associated with sectors of the input-output table. It is also desirable that there be no double-counting of weight. To illustrate, the beryllium used in beryllium-copper alloys would be weighed when refined, and then weighed again as a part of the output of the copper industry. It would be incorrect for the beryllium-copper in household appliances to have both weights ascribed to it.

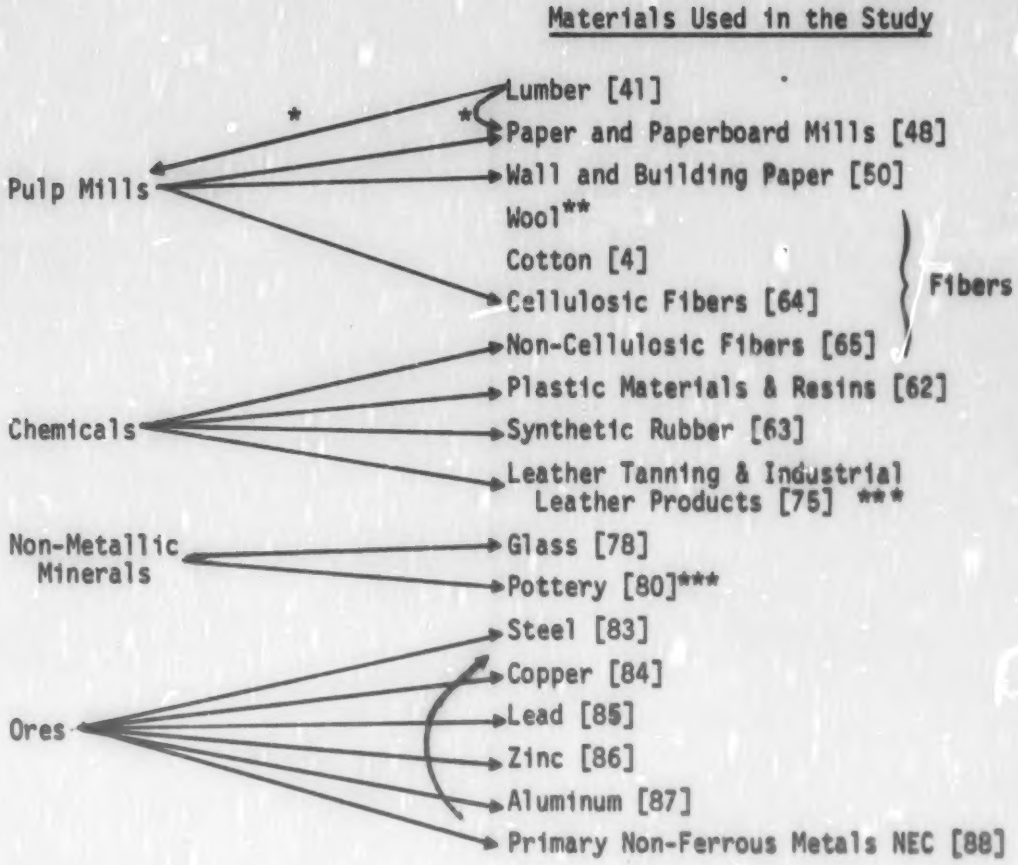
It is, in fact, not possible to find a set of input-output sectors that entails no double-counting of weight. Figure 4.1 shows the sectors that were selected, and identifies the two major cases of double-counting of weight: (1) alloying of metals, and (2) wood as an input of paper.

The double-counting of weight can occur in many ways, but the input-output table can help to identify specific cases. For example, the model locates every case in which any one of the 18 industries in Figure 4.1 sells to any other industry on the list. Each of these cases was analyzed to determine whether the weight would have been measured more than once. Any cases of double-weighing were then eliminated.

A more subtle case of double-counting of weight can occur within

FIGURE 4.1

FLOWS OF MATERIALS IN AN ECONOMY


Materials Used in the Study
Pulp Mills
*
*
Lumber [41]
Paper and Paperboard Mills [48]
Wall and Building Paper [50]
Wool**
Cotton [4]
Cellulosic Fibers [64]
Non-Cellulosic Fibers [65]
Fibers
Chemicals
Plastic Materials & Resins [62]
Synthetic Rubber [63]
Leather Tanning & Industrial Leather Products [75] ***
Non-Metallic Minerals
Glass [78]
Pottery [80]***
Ores
Steel [83]
Copper [84]
Lead [85]
Zinc [86]
Aluminum [87]
Primary Non-Ferrous Metals NEC [88]

* These flows were eliminated in advance.

** Does not fit available sectors.

*** Weight not available.

an industry. The measure of weight in the Census of Manufactures is the weight of shipments by plants in an industry. Whenever some plants in an industry sell a partially-finished material to other plants in the same industry, there would be double-counting of both sales and weight of products shipped by the industry. The input-output model identifies the amount of such sales within the industry (it is the diagonal term). This makes it possible to adjust for this form of double-counting of weight.

Table 4.1 gives the weight of production for the industries used in the study. Additional information and sources are given in Appendix B. The table includes adjustments for natural rubber and for metal produced from scrap (secondary production) as well as from ore (primary production). An adjustment is made for the quantity of industrial waste which does not become embodied in the final products.* Finally, any double-counting of weight is removed.

ALLOCATION TO HOUSEHOLDS: RESULTS OF THE STUDY

Table 4.2 shows the proportion of each material that is purchased (and hence disposed of) by consumer households.

In the analysis of possible errors in the input-output model discussed below, some of the allocations made by the model were classed as "uncertain". In those cases, it was possible for aggregation errors to occur and we were unable to provide the additional data required for accurate results. Table 4.2 shows the proportion of each material that was so classified. For many materials, the proportion is acceptably small. The uncertainty is substantial, however, for all metals except steel. Furthermore, it was not possible to provide results for individual fibers, so all fibers have been aggregated in Table 4.2.

Table 4.3 shows the amount of material, by end product, that is purchased (and eventually discarded) by consumer households. It

---

*According to the minimal method defined in Chapter 3, industrial scrap can be subtracted from the total weight of production. The adequacy of this assumption is investigated subsequently.

TABLE 4.1

WEIGHT OF PRODUCTION OF MATERIALS IN U. S. FOR 1971

INDUSTRY AND SECTOR	PRODUCED WEIGHT	SOURCE	DIAGONAL TERM	WASTE*	NET WEIGHT
Lumber and Wood Products [41]	121,600	2	n.a.	36,480	85,120
Paper and Paperboard Mills [48]	54,105	3	.0002	5,409	48,685
Wall and Building Paper [50]	3,444	3	.001	688	2,753
Plastic Materials [62]	9,237	4	n.a.	185	9,052
Synthetic Rubber [63]	2,461	5	n.a.	158	2,929***
Fibers (See below)					
Glass [78]	28,469	6,7	n.a.	nil	28,469
Steel [83]	125,981	9	n.a.	20,465	105,516
Copper [84]	2,072	10	n.a.	755	1,317
Lead [85]	1,435	10	n.a.	107	1,328
Zinc [86]	1,651	9	n.a.	279	1,372
Aluminum [87]	4,728	10	n.a.	781	3,947
Other Primary Non-Ferrous Metals [88]	1,645	3	.125	288	1,152
Fibers					
Wool [3]**	138	11		nil	138
Cotton [4]	2,115	11		nil	2,115
Cellulosic Fibers [64]	712	3		107	605
Non-cellulosic Fibers [65]	2,814	3		422	2,392

---

n/a: Weight of production not available

References given on Page 78.

Unit: Thousands of short tons

* Percentage waste is given in Table 4.20

** Wool is a small part of the production of this industry

*** Includes 626 of natural rubber.

TABLE 4.1 (Continued)

REFERENCES

1. Taken from input-output model used in INFORUM.

2. Phelps, Robert B. and Hair, Dwight, The Demand and Price Situation For Forest Products 1973-74, U. S. Department of Agriculture, Miscellaneous Publication No. 1292, September, 1974, Table 5, p.45.

3. U. S., Bureau of the Census, 1972 Census of Manufacturers, Preliminary Reports.

4. U. S. Tariff Commission, Synthetic Organic Chemicals, U. S. Production and Sales, 1971.

5. Stanford Research Institute, Chemical Economic Handbook Manual of Current Indicators, April 1972, p. 513.

6. Rubber Manufacturers Association, Statistical Report, December, 1974, p. 24.

7. Glass Containers Manufacturers Institute, Inc., Glass Containers, 1973-74.

8. Remainder of glass is obtained from inputs of glass manufacturers in the 1972 Census of Manufacturers, Preliminary Reports.

9. U. S., Bureau of Mines, Minerals Yearbook, 1971.

10. U. S., Bureau of Mines, Minerals Facts and Problems, Preprints. Data for 1971 is used.

11. Textile Organon, March, 1973, pp. 26-29.

TABLE 4.2

SOLID WASTE BY TYPE GOING TO CONSUMER HOUSEHOLDS

INDUSTRY AND SECTOR	NET PRODUCTION*	HOUSEHOLDS	UNCERTAIN	PERCENT GOING TO CONSUMER HOUSEHOLDS
LUMBER & WOOD PRODUCTS [41]	85,069	7,693	905	9 - 10
PAPER & PAPERBOARD MILLS [48]	48,659	29,064	871	60 - 62
WALL & BUILDING PAPER [50]	2,753	291	85	11 - 14
PLASTIC MATERIALS [62]	8,997	1,709	1,121	19 - 31
SYNTHETIC RUBBER [63]	2,992	1,330	152	44 - 50
GLASS [78]	28,469	9,405	1,237	33 - 37
STEEL [83]	105,516	25,690	914	24 - 25
COPPER [84]	1,313	49	100	4 - 11
LEAD [85]	1,328	220	200	17 - 32
ZINC [86]	1,372	11	438	1 - 33
ALUMINUM [87]	3,947	578	354	15 - 24
OTHER PRIMARY NON-FERROUS METALS [88]	1,070	217	162	20 - 35
FIBERS**	5,250	3,809		73

*Net production from Table 4.1 minus Double Weight from Table 4.6.

**Fibers included Cotton [4], Cellulosic Fibers [64], Non-cellulosic Fibers [65]

TABLE 4.3

MATERIALS GOING TO CONSUMER HOUSEHOLDS BY TYPE OF PRODUCT

INDUSTRY	LUMBER & WOOD PRODUCTS [41]	PAPER & PAPERBOARD MILLS [48]	WALL & BUILDING PAPER [50]	PLASTIC MATERIALS & RESINS [62]	SYNTHETIC RUBBER [63]	GLASS [78]	STEEL [83]	COPPER [84]	LEAD [85]	ZINC [86]	ALUMINUM [87]	OTHER PRIMARY NON FERROUS METALS [88]	FIBERS[1] [4][64][65]
TOTAL	7,693	29,064	291	1,709	1,330	9,405	25,690	49	220	11	578	217	3,809
CONTAINERS & PACKAGING		14,709	117	788		8,209	4,938				186		13
Food & Kindred Products [23 - 34]			117	788		7,813							13
Drugs [66]						396							
HOUSEHOLD DURABLES	874		1	136	28	286	3,812	2			70	4	315
Floor Coverings [36]													228
Furniture [45,46]	859						787						75
Household Appliances [123]	6		1	125	20	76	1,968	2			64		6
Radio & TV Receiving [125]	9			11	3	210	295				6	4	6
Farm Machinery (lawn mowers)[103]					5		543						
Service Industry Machinery [116]							219						
TRANSPORTATION	4,386		130	76	60	487	15,194	30	20	11	305	11	105
Motor Vehicles [133]				68	52	487	13,750	27	20		164	11	96
Trailer Coaches [140]	4,386		130	8	2		782	3		11	109		8
Cycles [139]					6		662				32		1
BUILDING													
Owner-Occupied Dwellings [167]	506		42	21	6	122	305	7					

*See second page

TABLE 4.3 (Continued)

MATERIALS GOING TO CONSUMER HOUSEHOLDS BY TYPE OF PRODUCT

INDUSTRY	LUMBER & WOOD PRODUCTS [41]	PAPER & PAPERBOARD MILLS [48]	WALL & BUILDING PAPER [50]	PLASTIC MATERIALS & RESINS [62]	SYNTHETIC RUBBER [63]	GLASS [78]	STEEL [83]	COPPER [84]	LEAD [85]	ZINC [86]	ALUMINUM [87]	OTHER PRIMARY NON FERROUS METALS [88]	FIBERS[1] [4][64][65]
MISCELLANEOUS	2,691	14.355	1	688	1,236	391	1,441	10	200		17	202	3,376
Products**	1,601	2,410		197	167								
Textiles & Apparel [35,37,38,39,40]													3,142
Tires [72]					988	7[3]	49						128[3]
Footwear & Leather Products [76,77]	259	79		101	52		9						53
Newspapers [52]		9,593											5
Periodicals [53]		1,407											
Books [54]		653											
Phonograph Records [126]				105									
Electrical Lighting [124]						46	208						
Batteries [129] [4]				2	4				196				
Optical Equip. [143]						10							
Watches, Clocks [146]				8			6					3	
Jewelry & Silverware [147]			1	15	1		48	10				199	3
Toys, Sporting Goods & Musical Instruments [148]	831	133		290	24	166	272		4		17		9
Other						79	888						36

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[1] Fibers includes Cotton [4], Cellulosic Fibers [64], and Non-cellulosic Fibers [65]. Because Wool [3] is such a small amount it is not included. See Textiles Organon.

[2] Included are Millwork & Wood Products [43], Paper Products, NEC [49], Rubber Products [73], and Misc. Plastic Products [74].

[3] Taken from actual data of Table 4.7 times .44 (the proportion of tires purchased by households).

[4] Recycled so not available in waste.

demonstrates the level of product detail that can be provided by input-output models.

Table 4.4 compares our results with two other estimates of the composition of solid waste. The comparison finds broad agreement between the various estimates. It is beyond the scope of this study to carry out a detailed analysis of any disparities, however. Such an analysis would entail an investigation not only of the differences between data sources, but also of the ways in which these sources are used.

The major difference between our results and others is the level of detail that is provided at the national level. To illustrate, Table 4.5 provides complete detail on the steel that occurs in household purchases (exclusive of transportation equipment, building maintenance, and metal containers). This table also shows the specific adjustments that were made to the quantities in the input-output table. It permits the reader to undertake his own sensitivity analysis concerning these adjustments -- he can see directly the consequence of changes in the adjustment ratios upon the estimate of steel in household solid waste.

The remainder of this chapter provides a justification for the adjustments that had to be made to the data in the input-output model in order to obtain the estimates given here.

ADJUSTMENTS TO THE INPUT-OUTPUT MODEL

We have noted that our method is to test the various assumptions of the minimal method, and then to make adjustments when necessary. Table 4.6 shows the amount of adjustment of each kind that was made for each material. The detailed adjustments are shown in Appendix B, Table B-3. The largest adjustments were those required to correct the assumption concerning constant price per pound. The next-largest adjustment concerned the assumption of prorating. The third largest adjustment concerned the assumption of an average rate of industrial waste.

Table 4.6 demonstrates conclusively that the composition of solid waste cannot be obtained directly from an inverse of the Embodied Submatrix. The first column in Table 4.6 is taken from such an inverse (i.e., from the approximation to an inverse that is provided by computing

TABLE 4.4

COMPARISON WITH OTHER RESULTS

MATERIALS		NCRR[1]	SMITH[2]	IR&T	
				HOUSEHOLD	COMMERCIAL*
PAPER	TOTAL	34.6	35.5	26.8	14.2
NEWSPRINT		6.9		9.6	
NEWSPAPER, BOOKS & MAGAZINES			9.3	11.7	
CONTAINERS & PACKAGING			18.5	14.8	
GLASS	TOTAL	9.8	11.0	9.4	3.1
CONTAINERS		8.8	10.1	8.2	
METALS	TOTAL	8.1	10.8	37.5	**
STEEL CONTAINERS		4.9	4.9	4.9	
STEEL OTHER		3.2	4.7	5.3	
ALUMINUM CONTAINERS		.23	.5	.19	
ALUMINUM OTHER		.34	.2	.39	
OTHER METALS		.41	.2	.5	
PLASTIC	TOTAL	2.0	2.9	1.7	1.0
CONTAINERS			2.3	.8	
CONTAINERS & FILM		1.7			
DURABLES		.09		.14	
TEXTILES	TOTAL	2.6	1.6	3.8	
WOOD	TOTAL		4.2	7.7	2.2
CONTAINERS			1.6		
FURNITURE			2.1	.9	
RUBBER		1.5		1.3	.5
RUBBER & LEATHER			2.9		

UNIT: Million Metric Tons

*Commercial sectors are identified in Appendix B, Table B-1a.

**This quantity is largely for activities that dispose of their own waste.

[1] "Municipal Solid Waste", NCRR Bulletin, Vol. III, No. 2, Spring, 1973, p. 5.

[2] Smith, Fred L., Jr., "Estimates of Household and Commercial Solid Wastes Based on Production Statistics." Draft Report. Resource Recovery Division, Office of Solid Waste Management Programs, U.S. E

[1] "Municipal Solid Waste", NCRR Bulletin, Vol. III, No. 2, Spring, 1973, p. 5.

[2] Smith, Fred L., Jr., "Estimates of Household and Commercial Solid Wastes Based on Production Statistics." Draft Report. Resource Recovery Division, Office of Solid Waste Management Programs, U.S. Environmental Protection Agency, June, 1974.

TABLE 4.5

STEEL INTO HOUSEHOLD DURABLES AND MISCELLANEOUS USES*

Industry and Almon Sector	Thousand Metric Tons**	Adjustment Factors for:			Adjusted Thousand Metric Tons
		Price	Industrial Scrap	Truncation	
TOTAL	5,270				5,254
OTHER ORDNANCE (GUNS) [22]	41	.51	.97	1.05	21
HOUSEHOLD & OTHER FURNITURE [45,46]	694	1.04	1.09	1.00	787
TIRES & INNER TUBES [72]	97	.51	1.00	1.00	49
OTHER LEATHER PRODUCTS [77]	22	.42	1.00	1.00	9
PLUMBING & HEATING EQUIPMENT [94]	28	1.02	1.13	1.00	33
STRUCTURAL METAL PRODUCTS [95]	38	.98	1.00	1.00	38
METAL STAMPINGS [97]***	283	1.15	.91	1.00	296
CUTLERY, HAND TOOLS & HARDWARE [98]	370	.55	1.00	1.00	203
MISC. FABRICATED WIRE PRODUCTS [99]	73	.82	1.00	1.00	60
OTHER FABRICATED METAL PRODUCTS [101]	76	1.00	1.00	1.00	76
ENGINES, TURBINES & GENERATORS [102]	110	.52	1.04	1.05	62
FARM MACHINERY (LAWN MOWERS) [103]	432	1.15	1.04	1.05	543
OTHER METAL WORKING MACHINERY [108]	41	.68	1.04	1.05	30
SERVICE INDUSTRY MACHINERY [116]	294	.68	1.04	1.05	218
HOUSEHOLD APPLIANCES [123]	1,638	1.05	1.04	1.05	1,969
ELECTRIC LIGHTING & WIRING EQUIPMENT [124]	178	1.08	1.03	1.05	208
RADIO & TV RECEIVING [125]	270	1.01	1.03	1.05	295
ENGINE ELECTRICAL EQUIPMENT [130]	30	1.01	.95	1.05	30
WATCHES, CLOCKS & PARTS [146]	21	.21	1.28	1.00	6
JEWLRY & SILVERWARE [147]	182	.21	1.28	1.00	49
TOYS, SPORTING GOODS & MUSICAL INSTRUMENTS [148]	352	.77	1.00	1.00	272

Source: Vol. II

* Does not include steel that goes into Containers, Transportation and Buildings.

** This tonnage is the weight given in the input-output table.

*** At least this amount of steel goes into Metal Stampings. This amount excludes all other metals that go into Metal Stampings. See Table 4.17.

TABLE 4. 6

AMOUNT OF ADJUSTMENT BY TYPE BY MATERIAL

INDUSTRY AND ALMON SECTOR	METRIC TONS*	ADJUSTMENTS MADE DUE TO:							REVISED METRIC TONS
		DOUBLE WEIGHT	NON-EMBODIED & TRANSFORMED DURING USE	SHIFTING CATEGORIES	PRORATING[1]	PRICE[1]	INDUS-TRIAL SCRAP	TRUNCATION	
LUMBER AND WOOD PRODUCTS [41]	11,248	- 51	- 140	± 175	- 905	6,303	648		7,693
PAPER AND PAPERBOARD MILLS [48]	22,453	- 26	- 480	± 2368	- 871	8,070	1,638	+ 1,337	29,064
WALL AND BUILDING PAPER [50]	376				- 85				291
PLASTIC MATERIALS [62]	2,844	- 55	- 37	± 6	- 1121	89		+ 71	1,709
SYNTHETIC RUBBER [63]	1,251	- 3	- 30	± 139	- 152	264			1,330
GLASS [78]	12,221				- 1237	1,579			9,405
STEEL [83]	27,009		- 24	± 102	- 914	2,938	2,789	+ 230	25,690
COPPER [84]	153	- 4			- 100	*	*	*	49
LEAD [85]	451		- 31	± 34	- 200	*	*	*	220
ZINC [86]	449				- 438	*	*	*	11
ALUMINUM [87]	938		- 15	± 3	- 354	82	27		578
OTHER PRIMARY NON-FERROUS METALS [88]	463	- 82	- 2		- 162	*	*	*	217
FIBERS COTTON [4]	1,841				- 1841	*	*	*	-
CELLULOSIC FIBERS [64]	449				- 360	*	*	*	89
NON-CELLULOSIC FIBERS [65]	1,788				- 1399	*	*	*	389

*No adjustment made because allocation to end use is very incomplete.

[1] The quantities in these columns represent the sum of absolute changes (positive or negative) of each term in Table B-3 of Appendix B.

path products). Many substantial adjustments were required before the final estimates were obtained.

The first type of adjustment, as described above, is the removal of cases in which the same material is weighed more than once. The adjustment involves a reduction in the weight of goods produced in an economy. This adjustment represented a significant proportion of output for only one material "other nonferrous metals". A large adjustment for lumber used in paper had been removed in advance.

The second type of adjustment is the identification of inputs that are nonembodied. The largest of these, in terms of percentage, is the lead used in printing. In most cases, the adjustment is small, representing very small percentages of the original estimates.

The third type of adjustment is the reassignment of end uses when they have been defined inaccurately from the viewpoint of final disposal. Some examples will illustrate what is involved. In our analysis, furniture and household appliances purchased and installed in house trailers were reassigned to furniture and household appliances, since they will be disposed of separately from house trailers. Batteries and tires were classified separately from motor vehicles, since they are or can be reclaimed separately from the motor vehicle carcass. The largest category of reassignment is containers and packaging material which is disposed of in a different form, and often much earlier, than the objects that they enclosed. This third type of adjustment did not change the weight of end products purchased by consumer households, but merely redefined the classification of end objects.

The fourth type of adjustment concerns the assumption of prorating. In the previous chapter, conditions were identified under which the use of prorating could give the wrong answer. The point is that the model computes with whatever information it has, and it is possible to define conditions under which the available information is insufficient for us to be able to trust the answers that are obtained. It will not be possible for us to provide the missing information, so it will be necessary merely to identify the results as "uncertain."

The difficulties caused by the prorating assumption are highly selective. For many materials, the effect is not substantial. For a number of materials, however, almost the entire result has to be classed as uncertain. The largest errors are for nonferrous metals and fibers.

Up to this point, all of the adjustments involve the redefinition of information in the input-output model. In many cases, information has been discarded because it represents non-embodied inputs, or because its accuracy is in doubt. Thus, our analysis consists of analyzing the meaning of the flows in an input-output table, selecting appropriate data, and reclassifying materials as needed. In order to adjust for the assumptions concerning average price and an average proportion of industrial waste, it is necessary to obtain data outside of the input-output table. This data provides coefficients which define the required adjustment. The adjustment can be either up or down. The quantities given in Table 4.6 represent the absolute value of change, as computed from the detailed tables in Appendix B. Table 4.6 shows that these adjustments were often very large. No adjustments were made for the materials which were substantially affected by prorating ambiguity.

The final adjustment is not an error of the input-output model, but a limitation of the method of computation that was used. The computation of path products can be exceptionally expensive unless it is truncated. The adjustment was inherently upwards, and it is significant only for the paper industry.

The first three types of adjustment (double-weight, nonembodied and shifting categories) do not require further discussion. Attention will now be focused on the other types of adjustment: prorating, price, and industrial waste. The adjustment for truncation is related to these, and will be discussed subsequently.

ERRORS DUE TO PRORATING: EXTENT AND SIGNIFICANCE

Chapter 3 notes that the computation of a matrix makes use of prorating and that, in the case of metal cans, such an assumption was found to be incorrect. This chapter identifies the extent of prorating error in the analysis, and also examines the significance of such error upon the results of the study.

Let us consider another example in which the assumption of prorating can be checked. Figure 4.2 shows the fibers that are used by Sector 37 (Miscellaneous Textiles) which sells fabric that is used in tires. These allocations can be tested because information is available on the weight of textile by type that is purchased by tire manufactures. Table 4.7 shows that in this case, the model is extremely inaccurate. In fact, the purchase of man-made fibers (cellulosic and non-cellulosic) by tires is closer to the inputs of this into Sector 37 than to the quanty computed by the model. Table 4.8 shows that this is reasonable, since most of the sectors included in Sector 37 are industries which purchase and process textile waste, or which aid plastics fabrics. Tire Fabrics are only 1/5 of the total sales of Sector 37 but this use accounts for a major part of the man-made yarns that are inputs to the industry.

Sector 37 has a number of inputs--various fibers, textile waste, and vinyl resins--and it has various uses, as shown in Table 4.8. Most purchasers from 37 use only some of the inputs into 37. Thus, tires mainly use man-made fibers; household textiles mainly use plastic resins; furniture mainly uses textile waste, etc. Such a selectivity is strikingly different from the assumption of prorating that is used when computing the model. The resulting errors are very large.

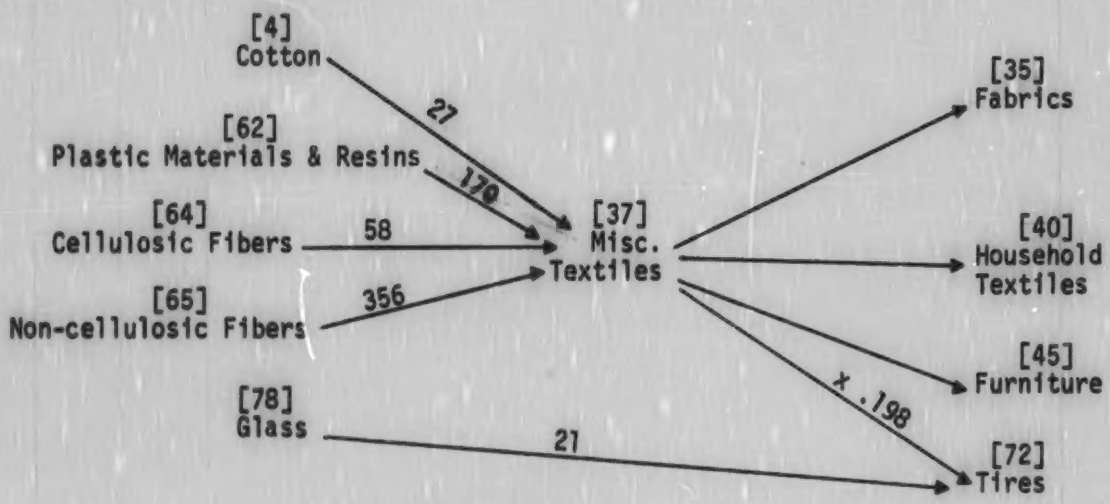
The assumption concerning prorating has been tested twice, and we can now see a general principle: The errors will be substantial for a material that has highly selective uses. When the model allocates aluminum to every use of cans, it produces highly unrealistic results. The errors for steel are less serious because metal cans are generally made of steel.

The conditions under which there can be no prorating errors were stated in Chapter 3 (Figure 3.2) and are the following:

1. If an industry sells solely to households, then every one of its inputs is embodied in purchases made by households.

FIGURE 4.2

FABRICS INTO TIRES



[4]
Cotton
27
[62]
Plastic Materials & Resins
179
[64]
Cellulosic Fibers
58
[65]
Non-cellulosic Fibers
356
[78]
Glass
21
[37]
Misc.
Textiles
[35]
Fabrics
[40]
Household
Textiles
[45]
Furniture
x .198
[72]
Tires

TABLE 4.7

FABRICS INTO TIRES

Fabric	Computed by the Model[1]	Actual[2]
Cotton	17	2
Cellulosic Fibers	15	46
Non-cellulosic Fibers	80	243
Fiberglass	21	17

Unit: Thousand Metric Tons

[1] Additional paths are included beyond those given in Figure 4.2.

[2] 1972 Census of Manufactures, Preliminary Report, Tires and Inner Tubes, p.4.

Note: Table 4.3 has these figures times .44, the proportion purchased by households.

TABLE 4.8

FIBER INPUTS OF THE DETAILED INDUSTRIES OF SECTOR 37

	2291 FELT GOODS N.E.C.	2292 LACE GOODS	2293 PADDING & UPHOLSTERY FILLING	2294 PROCESSED TEXTILE WASTE	2295 COATED FABRICS	2296 TIRE CORD & FABRIC	2298 CORDAGE TWINE
Rayon and cellulosic yarn		6.6				109.6	43.3
Other manmade yarn						312.4	
Cotton yarns							24.5
Other fibers (including waste)	54.7		73.9	55.3			
Raw cotton						*	
Raw wool	24.9						
Cotton waste			176.2	43.0			
Cotton linters			146.8				
Wool noils and waste	7.5			5.8			
Rags				39.8			
Vinyl resins					212.1		

Unit: Million pounds.

Source: 1967 Census of Manufactures, Volume I, p. 6-46.

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* The unit is in bales which are not weighed.

Diagrammatically, this is given by

$$i \longrightarrow j \xrightarrow{S} h_j$$

and the rule also holds for longer sequences:

$$i \longrightarrow j \xrightarrow{S} k \xrightarrow{S} m \xrightarrow{S} h_m$$

2. If an input i into j is necessary in the same ratio for every sale by j, then prorating is valid. Diagrammatically, this is given by

$$i \xrightarrow{N} j \longrightarrow$$

and this rule can also be extended to longer sequences:

$$i \xrightarrow{N} j \xrightarrow{N} k \xrightarrow{N} m \longrightarrow$$

3. A third rule is the combined rule which is given by

$$i \xrightarrow{N} j \longrightarrow k \xrightarrow{S} h_k$$

and by the possible extensions thereto.

The Extent of Prorating Error

It would be difficult to determine how many paths satisfy any of these three rules, and as such avoid prorating errors, since 1700 paths have been computed. We saw in Table 3.7 that 214 paths account for 3/4 of the output of each material that is purchased by consumer households. These 214 paths can be called the major paths. It is possible to determine the number of major paths that satisfies each of the three rules.

In applying the rules, a certain degree of approximation is permitted. In fact, we will err in permitting a generous degree of approximation, and then will identify where this has led to difficulties. Table 4.9 identifies all industries in the embodied portion of the economy which sell 85% or more to final demand. Some of these sell over 100% to final demand, because the ratio that has been computed is purchased by households as a proportion of domestic production. When the product is imported, then this ratio can be larger than one. Let us recall that each path product is computed according to

$$o_{ij} \times o_{jk} \times f_k$$

TABLE 4.9

INDUSTRIES THAT SELL ALMOST COMPLETELY TO CONSUMER HOUSEHOLDS

INDUSTRY	HOUSEHOLD PURCHASES AS A PROPORTION OF DOMESTIC PRODUCTION[1]	NUMBER OF MAJOR PATHS GOING TO INDUSTRY
MEAT PRODUCTS [23]	.8868	3
DAIRY PRODUCTS [24]	.8590	5
CANNED & FROZEN FOODS [25]	.9157	5
BAKERY PRODUCTS [27]	.9573	4
CONFECTIONERY PRODUCTS [29]	.9322	2
ALCOHOLIC BEVERAGES [30]	.9147	2
SOFT DRINKS & FLAVORINGS [31]	.9016	3
MISC FOOD PRODUCTS [33]	.9128	2
TOBACCO PRODUCTS [34]	.8852	2
HOSIERY & KNIT GOODS [38]		2
APPAREL [39]	1.0048	2
NEWSPAPERS [52]	1.0000	1
LEATHER FOOTWEAR (EXC. RUBBER)[76]	1.0988	2
OTHER LEATHER PRODUCTS [77]	.9652	2
RADIO & TV RECEIVING [125]	1.2113	1
PHONOGRAPH RECORDS [126]	.8904	1
CYCLES & PARTS, TRANSPORTATION EQUIPMENT [139]	1.1401	2
TRAILER COACHES [140]	.8905	7
WATCHES, CLOCKS & PARTS [146]	.9538	
JEWELRY & SILVERWARE [147]	.9884	2
TOYS, SPORTING GOODS + MUSICAL INSTRUMENTS [148]	.8794	6
OWNER-OCCUPIED DWELLINGS [167]	1.0000	3
HOUSEHOLD APPLIANCES [123]	.7958[2]	5

[1] This number can be larger than 1.0 when the product is imported.

[2] Included because an additional .0753 goes to real estate and trailer coaches.

where f_k is the proportion of sales to final demand. When f_k is greater than unity, as is found for radio and television sets, the computation correctly states that the materials purchased by U. S. firms to make radio and television sets will understate the materials that occur in household waste. When the quantity is less than 1.0, as it is for meat products, then the model is assuming that only a portion of U.S. production will become waste of households.

The other rule is that prorating is valid whenever material i into j is used in a fixed proportion by each use of j. This is a very strong assumption and will not necessarily be satisfied. It is satisfied when a specific material is processed through a number of steps, e.g., plastic resins into plastic products or synthetic rubber into rubber products. Other examples occur for wood and for paper. The assumption of fixed input proportions may be an aspect of design, e.g., rubber in a tire or steel in a motor vehicle. Table 4.10 lists the number of cases where these assumptions appear to be acceptable.

When several materials are substitutes, but the predominant weight is provided by one material, then most uses will consist of this predominant material. This rule applies to glass as the container for drugs and steel as an input into metal cans and metal stampings. However, this rule has to be checked carefully, because the lesser inputs may predominate in some of the special uses.

Several materials are never mentioned in Table 4.10--notably cotton, cellulosic fibers, non-cellulosic fibers, building paper, zinc, and other nonferrous metals. These materials will have no necessary input. By using Tables 4.9 and 4.10 as if they satisfied the pure rules cited above, it was possible to classify each of the major paths as satisfying or not satisfying the rules. Table 4.11 lists the number of major paths that satisfy each rule. A large number satisfy the rule of selling predominantly to final demand. Almost an equal number are satisfied by the other two rules--necessary inputs and the combined rule. The specific paths and assignment to each rule is given in Appendix B. When the paths were also studied to determine whether they were accurate even

TABLE 4.10

INPUTS THAT DO NOT RESULT IN PRORATING ERRORS

<table>
<tr><th colspan="4">SEQUENTIAL PROCESSING</th></tr>
<tr><td colspan="3">LUMBER [41]</td><td>VENEER & PLYWOOD [42]
MILLWORK & WOOD PRODUCTS [43]</td></tr>
<tr><td colspan="3">PAPER [48]</td><td>PAPER PRODUCTS, NEC [49]
PAPERBOARD CONTAINERS [51]</td></tr>
<tr><td colspan="3">PLASTIC MATERIALS [62]</td><td>PLASTIC PRODUCTS [74]</td></tr>
<tr><td colspan="3">RUBBER [63]</td><td>TIRES & INNER TUBES [72]
RUBBER PRODUCTS [73]</td></tr>
<tr><td colspan="3">STEEL [83]</td><td>METAL CANS [92]
METAL STAMPINGS [97]</td></tr>
<tr><th colspan="4">COMPL MENTATION</th></tr>
<tr><td colspan="3">PAPER [48]</td><td>BOOKS & PERIODICALS [53]
OTHER PRINTING SERVICES [54]</td></tr>
<tr><td colspan="3">STEEL [83]</td><td>HOUSEHOLD FURNITURE [45]
CUTLERY,HANDTOOLS, HARDWARE [98]
FARM MACHINERY [103]</td></tr>
<tr><td colspan="3">LEAD [85]</td><td>BATTERIES [129]</td></tr>
<tr><th colspan="4">EXCEPTIONS: PATHS GENERATED FROM THE ABOVE THAT ARE NOT ACCEPTABLE</th></tr>
<tr><td>[48]</td><td>[51]</td><td>[30]</td><td>The cartons remain at the retailers.</td></tr>
<tr><td>[83]</td><td>[92]</td><td>[30]</td><td rowspan="2">These are overstated (see Table 3.6)</td></tr>
<tr><td>[83]</td><td>[92]</td><td>[31]</td></tr>
<tr><td>[83]</td><td>[97]</td><td></td><td>Minor inputs of metals into stampings (aluminum and copper) sell to final demand but they are purchased in insufficient volume (see Table 4.16) to account for all stampings to households, so this path is partly correct.</td></tr>
</table>

Note: [30] ALCOHOLIC BEVERAGES
[31] SOFT DRINKS & FLAVORINGS

TABLE 4.11

MAJOR PATHS THAT SATISFY AND FAIL TO SATISFY PRORATING CRITERIA

	Number of Major Paths	Sole Use by Final Demand	Necessary Input	Combined Rule	Questionable
COTTON [4]	6	0	0	0	6
LUMBER [41]	5	2	2	1	0
PAPER & PAPERBOARD MILLS [48]	14	1	3	7	3
BUILDING PAPER MILLS [50]	7	5	0	0	2
PLASTIC MATERIALS & RESINS [62]	35	8	3	12	12
SYNTHETIC RUBBER [63]	4	0	3	0	1
CELLULOSIC FIBERS [64]	8	2	0	0	6
NON-CELLULOSIC FIBERS [65]	8	2	0	0	6
LEATHER [75]	2	2	0	0	0
GLASS [78]	5	3	1	0	1
POTTERY [80]	1	0	0	0	1
STEEL [83]	13	4	5 1/2*	3	1/2*
COPPER [84]	21	4	1	0	16
LEAC [85]	20	1	2	0	17
ZINC [86]	35	1	0	0	34
ALUMINUM [87]	18	4	1	0	13
OTHER METALS [88]	12	1	1	0	10
	214	40	22 1/2	23	128 1/2

*Steel is the predominant metal used in stampings but other metals are frequently used for stamped consumer objects. The steel allocated to household stamped objects is 447 thousand metric tons (see Appendix C, page C-43, line 32). The possible materials that might be used in place of steel (see Table 4.16) are less than half of this, so the allocation is at least 1/2 correct.

when they satisfied the rules, a number of exceptions were found.

Of the original 216 major paths, approximately 85 involve no substantial prorating error. However, for a number of materials, all or most of the paths are acceptable. The assumption of prorating introduces little or no error for lumber, paper, rubber, leather, glass, and steel. Almost all of the difficulties are with plastics, fibers (cotton, cellulosic, non-cellulosic) and metals other than steel. This is a most important result. Whereas it might appear that prorating errors would eliminate the usefulness of the input-output model, it can be seen that many materials encounter little or no difficulty because of prorating. The difficulty is confined to a limited number of materials.

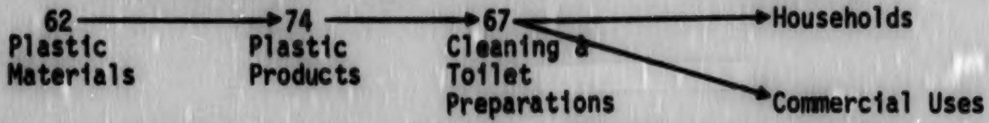
The results are not necessarily inaccurate when none of these criteria are satisfied. The situation is that the results may still be accurate, but only accidentally so. There is no reason for the results to be accurate, since the assumption of prorating is entirely arbitrary. This means that the results of the model cannot be trusted.

Table 4.11 identifies three major problem areas: plastics [62], fibers [4], [64] and [65], and metals [83], [84], [85], [86], [87], and [88]. A discussion of these areas will reveal more clearly the difficulty that can arise from the assumption of prorating.

Prorating Flows of Plastics

A large number of paths were computed to allocate plastics to households--180 paths in all. Thirty five were major paths, and of these 23 are acceptable and 12 are questionable. We will now consider these questionable major paths of plastics.

The largest questionable path from plastics is the following:



Plastic is a material used as a container. The competitive materials are glass bottles and aerosol metal cans. Table 4.12 shows the various packaging materials that are used by this industry. The largest amounts

TABLE 4.12

VARIOUS PACKAGING MATERIALS USED BY SECTOR 67 CLEANING & TOILET PREPARATIONS IN 1971

					Weight
48	Paper Mills →	49	Paper Products →	67	80
48	Paper Mills →	51	Paperboard Containers →	67	462
62	Plastic Materials →	74	Plastic Products →	67	151
62	Plastic Materials →			67	37
78	Glass →			67	571
83	Steel →	92	Metal Cans →	67	291
83	Steel →	93	Metal Barrels →	67	48
87	Aluminum →	92	Metal Cans →	67	8

Unit: Thousand metric tons
Source: Path Products from Appendix C

by weight are glass, paper, and metal cans. Plastic containers are used less frequently.

Of all the sales of Sector 67 (Cleaning and Toilet Preparations), 75% go to consumer households. The remainder go to commercial establishments such as laundries, hair dressers, and hospitals. Most commercial users are less concerned with bottle style and, therefore, are accepting plastics more readily than households. Hence the assumption of prorating probably overstates the amount of plastic in household waste.

Table 4.13 provides a similar analysis of each of the questionable major paths for plastics. When the product mix (the mixture of products produced by an industry) is very large, it is very difficult to estimate the direction of adjustment that is required.

In general, the size of the adjustments for plastics is not substantial. Many of these industries sell approximately 3/4 of their products to households; therefore, the household composition generally includes some plastic.

Why is the analysis of plastic less accurate than that of the other materials? Many materials have uses for which they are the dominant (or perhaps necessary) inputs. Some examples are shown by the following sequences:

wood ⟶ veneer and millwork
rubber ⟶ tires
paper ⟶ newspapers, books
steel ⟶ most durables

These materials have no serious competitors in the indicated markets. Plastic does not dominate any major market but is in the process of invading a large number of different markets. This means that it is almost always a competitor of other materials. Furthermore, it has invaded its markets unevenly. Since having a competitor and not being used homogeneously are two criteria that will result in prorating errors, plastic has many more prorating errors than many other materials.

Containers and Packaging

Several of the questionable paths of plastics are examples of con-

TABLE 4.13

PATHS OF PLASTICS THAT ARE POTENTIALLY INACCURATE

PATHS	ALTERNATIVE MATERIALS	SERIOUS PRODUCT MIX[4]	OTHER USES	REQUIRED ADJUSTMENT
62 74 67	glass, metal		laundries,	down
62 67	paper		hair dressers	up
62 49[1]		yes	packaging	
62 74 49[1]		yes		
62 74 45	wood, metal	yes	offices	down
62 45				
62 74 133[2]	steel		trucks, industrial fleets taxicabs	up
62 133[2]				
62 68 167	oil-base paint			up
62 150		yes	apparel	
62 74 66	glass		doctors	down
62 74 40[3]		yes	motor vehicles seat covers	
62 128 125		yes	communications equipment	
62 74 128 125				

[1] The 1967 Census of Manufactures (p. 26B-32) shows that most of this is for SIC 2643 and would be for combination bags.

[2] These paths were accepted because the adjustment was slightly upward.

[3] Largely for shower curtains and table cloths by SIC 2392.

Names of Industries:

40	Household Textiles
45	Household Furniture
49	Paper Products, NEC
62	Plastic Materials and Resins
66	Drugs
67	Cleaning and Toilet Preparations
68	Paints
74	Misc. Plastic Products
125	Radio and TV Receiving
128	Electronic Components
133	Motor Vehicles and Parts
150	Misc. Manufacturing, NEC
167	Owner-Occupied Dwellings

[4] Most of the products produced by the industry do not contain plastics, so the possibility of prorating error is very large.

tainers or packaging. Since many different materials are used in some form of packaging, they have a number of problems in common that deserve attention.

The analysis of containers and packaging is prone to prorating errors because for virtually anything that requires packaging or containerization, there are satisfactory alternatives among the available materials: wooden boxes or paperboard containers; plastic, glass, or metal containers; and paper or cellophane wrapping. Different users will have different reasons for selecting one or another type of packaging. In particular, there will be major differences in the packaging required by bulk (industrial) purchasers as opposed to households.

A certain number of obvious difficulties are readily corrected. For example, wood containers and metal barrels seldom reach households because they are used almost exclusively by industrial and commercial users. Furthermore, the following sequence can be defined as unacceptable:

$$\text{Container or packaging} \longrightarrow i \longrightarrow j \longrightarrow h_j,$$

since if a product i has been packaged and then is used as an input of j, the packaging will not be sent on to households but will end at the industrial installation of j.

There are at least three difficulties that are less readily corrected. First, consumer households generally use goods that are more intricately packaged than those which go to industrial and commercial users. The model prorates packaging to all users, thereby allocating less packaging to consumer households than is used by them.

Second, there is undoubtedly a difference between commercial users and households in the mix of packaging that is used. The difference is not readily defined or corrected for. Third, a difficulty arises from the treatment of trade margins in the input-output model. Wholesale and retail trade are not listed as receiving commodities, but only as providing a service to users. Some packaging is removed by wholesalers and retailers, whereas the model assigns such packaging to households. Furthermore, paperboard cartons are not distinguishable as such, but are a part of an industry that makes boxes of all kinds, so they are not readily reassigned to commercial use. No correction has been made for these three types of difficulty.*

Prorating Flows of Fibers

Figure 4.3 shows the major sales of fibers and textiles. Table 4.14 gives the sales of textiles to one another, and the sales of various materials to textiles. The sales of Apparel [39] are almost solely to households, and the sales of Hosiery and Knit Goods [38] are predominantly to households and Apparel. Together these sectors satisfy the completeness rule, but no other textile sector has as much as 65% of its sales going to households plus[38] and [39].

The fibers used in textiles are alternatives to one another, and in any case, their major paths proceed through Broad and Narrow Fabrics [35] as shown in Table 4.15. Sector 35 purchases each type of fiber and sells to the other textile sectors. There is no reason to believe that the assumption of prorating is valid here. For example, most Hosiery and Knit Goods [38] might be predominantly made of one of these inputs. Without additional information on the fibers used by end uses, we cannot rely upon the computations of the model.

Since finished textile products must be composed of some fiber, then it seems plausible that the amount of *fiber of all kinds* can be accepted from the allocations of the input-output model. The proportion of each type of fiber going to households is approximately 80%. It can be inferred that the *weight of fibers of all kinds* in household waste is this percentage of the inputs of fibers into all textiles.

It has already been noted that the heat content of different fibers is very different. The inability of the input-output model to allocate types of fiber to end uses means that it is *not possible to infer the heat content* of the textiles disposed of by consumer households.

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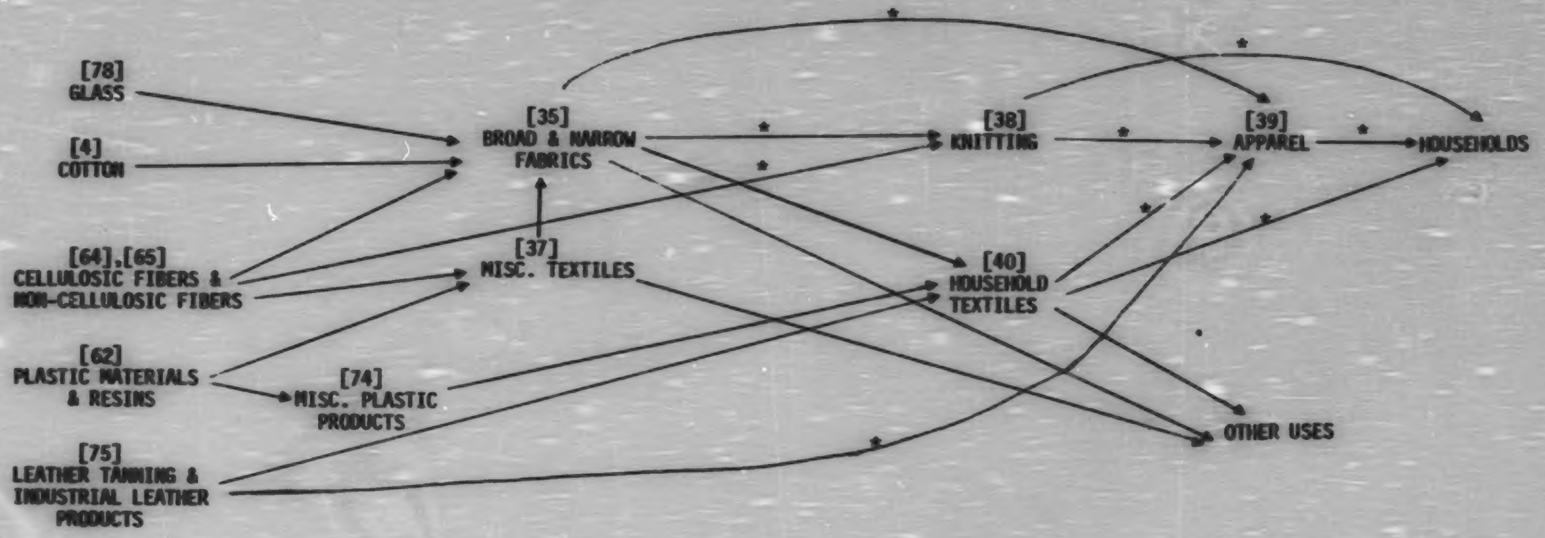
*A detailed analysis of packaging is provided by Research Triangle Institute, An Evaluation of the Costs and Effectiveness of Regulatory and Fiscal Strategies on Product Packaging, Draft Final Report, October, 1973.

FIGURE 4.3

MAJOR FLOWS INTO TEXTILES


[78]
GLASS
[4]
COTTON
[64],[65]
CELLULOSIC FIBERS &
NON-CELLULOSIC FIBERS
[62]
PLASTIC MATERIALS
& RESINS
[74]
MISC. PLASTIC
PRODUCTS
[75]
LEATHER TANNING &
INDUSTRIAL LEATHER
PRODUCTS
[35]
BROAD & NARROW
FABRICS
[37]
MISC. TEXTILES
[38]
KNITTING
[40]
HOUSEHOLD
TEXTILES
[39]
APPAREL
HOUSEHOLDS
OTHER USES
*

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* acceptable path product

TABLE 4.14

INPUTS TO TEXTILES

INDUSTRY AND SECTOR	35	36	37	38	39	40		
TEXTILES								
Fabrics, Yarns & Thread Mills [35]	+	.083561	.010012	.126362	.423861	.157263	.078659	.628882
Floor Coverings [36]		+	.000874				.633059	.633059
Misc. Textiles [37]	.146543	.056228	+		.036610	.208469	.056262	.092872
Hosiery & Knit Goods [38]			.022225	+	.359086	.021225	.587939	.947025
Apparel [39]	.000748	.000074	.000056		+	.000209	.004822	1.004822
Household Textiles [40]		.006678	.004738		.098114	+	.506873	.604987
FIBERS								
Wool [3]	.005485	.003020	.008228				.014248	.014248
Cotton [4]	.514006		.007569				-	-
Cellulosic Fibers [64]	.629517	.014083	.105970	.170302		.016324	-	.170302
Non-Cellulosic Fibers [65]	.524864	.102396	.164083	.188923		.011608	-	.188923
OTHER INPUTS								
Paper [48]			.000347	.000134			.004702	.001836
Plastic Materials [62]	.003847		.021061			.000558	.001661	.001661
Plastic Products [74]	.001459		.000703	.000575	.000390	.014183	.053051	.054016
Synthetic Rubber [63]		.051340	.000531				-	-
Leather [75]				.000714	.074549	.022169	-	.075263
Glass [78]	.016678		.001003				.086690	.086690

TABLE 4.15

MAJOR PATHS OF FIBERS IN SIZE ORDER

INPUT FIBER	REMAINDER OF PATH
4 or 64 or 65	35 → 39
64 or 65	38
64 or 65	38 → 39
65	36
4 or 64 or 65	35 → 40
4 or 64 or 65	35
4 or 64 or 65	35 → 38
4 or 64 or 65	35 → 36
4 or 64 or 65	35 → 38 → 39

Source: Appendix C

4	Cotton
64	Cellulosic Fibers
65	Non-Cellulosic Fibers
35	Broad and Narrow Fabrics
36	Floor Coverings
38	Knitting
39	Apparel
40	Household Textiles

Prorating Flows of Metals

There is a considerable similarity between the difficulties of allocating flows of metals, and those of allocating flows of fibers. In each case, there are some sales direct to finished products, but there are also substantial sales of competing materials to sectors that process these materials. Table 4.16 lists some of the major processing sectors and the metals which sell substantially to them.

There are two differences, however. First, metals are not as dependent upon consumer households as they are upon capital equipment. This means that to the extent that there are prorating errors, some metals may be used almost entirely in capital equipment and do not occur at all in household waste, or the reverse might be the case.

The other difference is that the preponderance of one metal, steel, is such that all other metals have quite specialized uses. Table 4.1 shows that steel accounts for over 90% of the weight of all metals. Steel is not only stronger than the other metals but also much cheaper. The other materials are used only when steel cannot be substituted. An example is zinc, which is sold to steel in order to galvanize a limited number of objects, especially building materials. The prorating assumption assigns zinc to all uses of steel, rather than to the small subset where it is used as protection against weathering. Similarly, aluminum and copper stampings have very specific uses (e.g., frying pans), but are assumed to be a part of the composition of every product for which stampings are used.

The result is a very large number of paths, most of which are false. An extreme example is that the sales of lead to industrial chemicals is converted into 100 paths, every one of which is false! Lead is used almost solely for the tetraethyl lead that is an additive of gasolines, and since gasoline is not embodied, there should have been no path at all.

With the exception of steel, the metal sectors need to be replaced with flows that associate the metals directly with the end products that make use of their special properties.

TABLE 4.16

METALS SOLD TO METAL PROCESSING SECTORS

	NON-FERROUS ROLLING & DRAWING,NEC [89]	NON-FERROUS WIRE DRAWING & INSULATING [90]	NON-FERROUS CASTINGS & FORGINGS [91]	METAL CANS [92	PLUMBING & HEATING EQUIPMENT [94]	STRUCTURAL METAL PRODUCTS [95]	SCREW MACHINE PRODUCTS [96]	METAL STAMPINGS [97]	CUTLERY HAND TOOLS & HARDWARE [98]	VALVES,PIPE FITTINGS, & FABRICATED PIPE [100]	OTHER FABRICATED METAL PRODUCTS,NEC [101]	ENGINES & TURBINES [102]
STEEL [83]	14.4		30.2	6,393.8	853.5	13,837.6	1,896.0	8,436.9	1,997.5	1,977.3	1,727.9	2,489.4
COPPER [84]	2.6	335.1	2.9		49.8	34.1	30.4	30.1	20.0	70.5	3.4	15.5
LEAD [85]	81.0	88.3	8.2			35.5				3.0	26.4	
ZINC [86]	62.0		342.7			13.3	5.0	17.7	216.4	62.7	71.8	
ALUMINUM [87]	2.4	195.2	65.0	171.6	12.0	639.3	37.4	155.9	42.3	18.1	134.8	106.0
OTHER PRIMARY NON-FERROUS METALS [88]	355.9	1.2	4.8			15.0				40.1	70.6	

Source: Appendix C.

THE ADJUSTMENT FOR AVERAGE PRICE PER POUND

Our interest is in the weight of solid waste,and the input-output model is based upon the value of sales. We have converted from value to weight by computing the proportion of output and multiplying by the tonnage of production of the material. This is acceptable to the extent that each purchaser of a material is paying the same average price, since value of sales is being used as a surrogate of weight. If different users pay substantially different prices, then an adjustment needs to be made. The size of the adjustment--the largest of any kind required for this analysis--can be seen in Table 4.6 above. The present discussion identifies why the adjustment for price has to be so large.

Tables 4.17 and 4.18 show the range of prices paid by purchasers of steel and aluminum respectively. It is apparent that the difference can be very large. The average price of steel is $200 per ton; however, some important industries pay $150 per ton or less. There are also industries that pay as much as $1000 per ton. The range of prices for aluminum is not as extreme, but does involve a five-fold difference in price paid by different industries. This means that the numbers of the input-output model must be increased substantially in some cases (multiplied by 1.4 or more). In other cases, because they have sharply overstated the weight of steel and aluminum, the numbers must be multiplied by 0.3 or 0.2.

What is the reason for such extreme differences in price paid by different users? How can the "same" material be sold at such different prices? The answer is that the purchasers are actually buying quite different materials. When a purchaser pays less than average, he is buying a low-cost grade of steel in a basic, unfinished form. The purchasers that pay much more than average are purchasing significant quantities of high-alloy steel and aluminum. Stainless steel generally costs over $1000 per ton, so if an industry is mainly purchasing stainless steel, it would be paying much more. The alloys that are used for aircraft have a particularly high proportion of alloy additives, and these cost much more than the iron ore used in carbon steel and low-alloy aluminum.

TABLE 4.17

RANGE OF STEEL PRICES BY USER INDUSTRY

SIC NUMBER	INDUSTRY NAME	$1,000 PER SHORT TON	ADJUSTMENT FACTOR
	Prices Lower Than Average		
3632	Refrigerators	.10	2.0
3449	Miscellaneous Metalwork	.14	1.4
3446	Architectural Metalwork	.15	1.3
3491	Metal Barrels, Drums, Pails	.15	1.3
3272	Concrete Products	.15	1.3
2522	Metal Office Furniture	.16	1.2
3441	Fabricated Structural Steel	.16	1.2
3741	Locomotives	.16	1.2
3731	Ship Buildings	.16	1.2
3639	Household Appliances, nec	.16	1.2
3714	Motor Vehicle Parts	.17	1.2
3751	Motorcycles, Bicycles	.17	1.2
	Average Price	.20	
	Prices Higher Than Average[1]		
3729	Aircraft Equipment nec	.53	.38
1961	Small Arms Ammunition	.55	.36
3421	Cutlery	.56	.36
3699	Electrical Equipment nec	.63	.32
3674	Semiconductors	.65	.31
1931	Tanks	.68	.29
3673	Electron Tubes	.74	.27
3545	Machine Tool Accessories	.86	.23
3914	Silverware	.92	.22
3722	Aircraft Engines	.93	.22
3831	Optical Instruments	1.00	.20
3425	Handsaws	1.05	.19

[1] 3301 and 3942 omitted because data are questionable.

SOURCE: 1967 Census of Manufactures. See Appendix B, Table B-4.

TABLE 4.18

RANGE OF ALUMINUM PRICE BY USER INDUSTRY

SIC NUMBER	INDUSTRY NAME	PRICE PER POUND	ADJUSTMENT FACTOR
	Prices Lower Than Average		
3941	Games and Toys	.31	1.58
3621	Motors and Generators	.34	1.44
3411	Metal Cans	.35	1.40
3633	Household Laundry Equipment	.35	1.40
3644	Noncurrent-Carrying Wiring Devices	.36	1.36
3444	Sheet Metalwork	.38	1.29
3357	Nonferrous Wiredrawing & Insulating	.38	1.29
3564	Blowers and Fans	.39	1.26
3442	Sheet Metalwork	.40	1.22
3643	Current-Carrying Wiring Devices	.40	1.22
	Average Price	.49	
	Prices Higher Than Average		
3545	Machine Tool Accessories	.83	.59
1925	Complete Guided Missiles	.84	.58
3533	Oilfield Machinery	.85	.58
3751	Motorcycles, Bicycles and Parts	.85	.58
3821	Mechanical Measuring Devices	.86	.57
3572	Typewriters	.86	.57
3541	Machine Tools, Metal-Cutting Types	.89	.55
3721	Aircraft	.91	.54
3573	Electronic Computing Equipment	.94	.52
3831	Optical Instruments and Lenses	1.07	.46
3579	Office Machines, nec	1.50	.33
3673	Electron Tubes, Transmitting	1.75	.28

SOURCE: 1967 Census of Manufactures, See Appendix B, Table B-4.

Table 4.19 shows the ranges of prices paid for various materials. It is apparent that the ranges of prices paid for steel and aluminum are not unusual, but that many materials have similar variations in price. There can be at least four reasons for a material to be inexpensive:

a. It requires few or no additives,

b. The specific grade of material is produced in large volume,

c. Purchases are made in volume,

d. It is made with a cheap filler such as scrap or byproducts.

An example of a cheap filler is the plastic used for toys which often includes scrap plastic (which is cheap since it has few uses). In the case of leather, the splits (the inside layer of hide) are cheaper than the grain (outside) layer.

High prices will be paid when any one of these reasons is not satisfied. The largest increases in price, however, come from the use of expensive additives. We have seen the effect of alloy additives upon the prices of steel and aluminum. Other examples of additives are various materials that whiten paper, tan leather in special ways, color plastic or make plastic fire resistant.

Table 4.19 shows that the variation toward higher and lower prices is not equal. The bias is towards higher prices because some users have exceptionally demanding requirements which require special skills, special machinery and/or expensive additives. When a user pays a price per pound for a material that is sharply higher than average, it should be possible to identify, at least qualitatively, the inputs (materials, labor, machinery or trade margins) that are used in unusual quantities to produce the material being pruchased.

There is a very significant relationship between adjustment for average price and adjustment of prorating errors. Prorating errors are most serious when special materials (e.g., chromium, glass fibers) are an input into sector i. Their unusual properties generally mean that they are needed and used by a very limited number of purchasers from i. In order to correct the model's assumption of prorating in such cases, it

TABLE 4.19

RANGES OF PRICES FOR SELECTED MATERIALS

	ALL USES			MAJOR USES					
	Lowest Price	Average Price	Highest Price	Price	Large User	Price	Special User	Adj. for Major User	Adj. for Special User
STEEL[1]	.10	.20	2.58[3]	.17	Motor Vehicles	.25	Machinery	1.2	0.8
ALUMINUM[1]	.31	.49	1.75	.38	Wire	.91	Aircraft	1.3	0.5
LUMBER[1]	.07	.19	.70	.11	Trailer Coaches	.70	Furniture	1.7	0.3
PAPER[2]	.09	.17	.50	.13	Newsprint	.26	Book Paper	1.3	0.7
PLASTICS[2]	.12	.24	1.65	.13	PVC	.24	Thermosetting Resins	1.8	1.0
PLASTICS[1]	.20	.28	.88	.23	Plastic Products	.33	Motor Vehicles	1.2	0.8
RUBBER[2]	.17	.26	2.72	.19	Tires	.46	Butadiene/ Acrylonitrile	1.4	0.6
LEATHER[2]	.22	.46	.81	.37	Garment Leather	.49	Upper shoe grains	1.2	0.9

Source: Appendix B

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[1] Data on average price paid per industry

[2] Data on average price of type of product

[3] Stainless steel for aircraft engines, 1967, Census of Manufactures, Vol. I, pp. 6-15.

is necessary to associate the special inputs into i with the specific users who purchase from i. These purchasers reveal themselves by paying a much higher average price per pound for the materials that they purchase from i. This means that an analysis of the price per pound being paid by various users of materials is a method for beginning to connect some detailed inputs of various materials with the specific indirect users that require the products in which these materials are embodied.

The method described here involves the computation of various ratios, so that comparisons can be made to identify the major differences which must be regarded as indicators of phenomena requiring explanation. The explanations give us a better understanding of the structural relationships in the economy. In this case, ratios of one kind (price per pound) can help us to identify relationships of a different kind (the indirect use of materials). It would appear that analysis of this kind should be a common procedure in economics.

THE ADJUSTMENT FOR INDUSTRIAL WASTE

In the minimal method used in this study, the waste generated during production was handled by subtracting it from production. Such a procedure assumes implicitly that the same proportion of waste has occurred during the production of every end product--that is, if the average rate of industrial waste is 10%, then every end product contains 10% less material than was purchased in order to produce the end product.

The adjustment for actual rates of industrial waste is given by

$$\frac{1 - \text{actual rate}}{1 - \text{average rate}}$$

The adjustment would be very small when the rates are low, since the numerator and denominator would then be near unity. Obviously, the adjustment would also be small when there tends to be an average rate of waste and every user has approximately the same rate of waste. Table 4.20 shows the average, low, and high rates when data has been found. Three materials--plastics, rubber and glass--have sufficiently low waste rates that no adjustment was required. Adjustments were made for the other materials where data exists, as discussed in Appendix B. The

TABLE 4.20

WASTE RATES FOR VARIOUS MATERIALS

INDUSTRY and SECTOR	AVERAGE	LOW	HIGH
Lumber and Wood Products [41]	.3	.25	.6
Paper and Paperboard Mills [41]	.1	.025	.19
Wall and Building Paper [50]	.2	*	*
Plastic Materials [62]	.02	.005	.04
Synthetic Rubber [63]	.05	.01	.09
Fibers (see below)			
Glass [78]	nil	nil	nil
Steel [83]	.16	.03	.31
Copper [84]	.36	*	*
Lead [85]	.07	*	*
Zinc [86]	.17	*	*
Aluminum [87]	.17	.11	.48
Other Metals [88]	.20	*	*
Fibers			
Cellulosic Fibers [64]	.15	*	*
Non-cellulosic Fibers [65]	.15	*	*

*Data not obtained

adjustments for paper were never large, but the adjustments for lumber were reasonably substantial. No adjustment was made for those materials that had major amounts of prorating difficulty, such as copper, zinc, aluminum, other metals, and fibers.

Information on waste rates is scarce. Also, much of it is dated (e.g., metal data is based upon a 1954 survey) and is of questionable reliability. Therefore, the data should be supplemented by a discussion of the technology of waste generation. Waste will be low when the process involves joining (e.g., making boilers) or pouring (as with plastics or glass). It will also be low when the material is melted during production, as is glass. It is largest when the material is cut which often happens with metal and always happens with wood and paper.

Because of lack of data, no adjustment was made for later stages of production.* This type of waste occurs largely from rejection of parts, and this was felt to involve a low rate of waste. The available data on waste was sufficiently approximate and out of date that such an adjustment was felt to be an unnecessary refinement.

TRUNCATION

Path products have been found to be useful in a number of ways:

(1) They provide an approximate inverse matrix very efficiently.

(2) They test sensitivity by identifying which paths have the largest effect upon the answer. They also show which indirect impacts will be affected by a change in any specific input coefficients.

(3) They provide information by which the input-output model can be tested since paths implicit in the model should match sequential production in an economy.

(4) Path products can be adjusted directly to take account of any changes that are found to be required.

We have already been warned, however, that these benefits may not be available unless a complete set of path products is available. Furthermore, it has been pointed out that a complete set of path products could not be computed because there were too many, most of which contribute very little to the answer. We will now analyze the extent to which this causes difficulty for our analysis.

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*This topic is discussed in Chapter 3, p. 49.

The adequacy of path products depends upon the type of structure that is being represented. The computation of path products is most effective when the matrix is sparse and represents a series of one-way flows. The computation of path products is particularly unsuitable for a matrix that is highly interdependent. Different parts of the economy vary widely in the extent to which their elements are structurally interdependent. Embodied inputs consist of sequences of one-way flows that involve the steps of extraction, refining, processing (one or more steps) and assembly into finished components and finished objects. There are many different materials undergoing a similar sequence of steps. Path products are ideal for representing sequences of this kind.

Overhead expenditure involves a very different structure. Almost every industry has the same kind of overhead expenditures: insurance, transportation costs, advertising, fuel, office expenses, etc. The industries providing overhead, therefore, sell to many or most of the other industries in the economy. Furthermore, these sectors sell quite heavily to one another. Together, these patterns mean that as the length of the path increases, the number of paths increases dramatically. Since these sectors are interdependent (i.e., have cycles), it would be possible to generate paths of any length--and any number. Fortunately, our analysis is concerned with embodied inputs, where the method of path products is quite suitable, and is not involved with overhead expenditure which is nonembodied.
nonembodied.

Because of the existance of cycles, which permit paths of infinite length, it is necessary to introduce some method of ending the computation. The method used in the study is to define a threshhold and then to retain no path product smaller than this threshhold. This means that the number of paths is incomplete--it is trucated. Table 4.21 shows the proportion of output that is lost because of this truncation. It is important to emphasize that the results in this table are for the

TABLE 4.21

PROPORTION OF SALES LOST FROM TRUNCATION

INDUSTRY AND SECTOR	LOST BY TRUNCATION *
COTTON [4]	.09
LUMBER [41]	.20
PAPER [48]	.32
WALL & BUILDING PAPER [50]	.11
PLASTICS [62]	.27
RUBBER [63]	.19
CELLULOSIC FIBERS [64]	.12
NON-CELLULOSIC FIBERS [65]	.12
LEATHER [75]	.06
GLASS [78]	.13
POTTERY [80]	.13
STEEL [83]	.26
COPPER [84]	.21
LEAD [85]	.38
ZINC [86]	.44
ALUMINUM [87]	.22
OTHER METALS [88]	.39

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*This overstates the loss for two reasons: (a) this is from the entire matrix and the loss for the Embodied Submatrix would be another; (b) prorating errors result in an overstatement of loss.

entire input-output matrix and not for the Embodied Submatrix. A comparable table for the Embodied Submatrix has not been computed. Some of the loss for rubber, then, is for tires purchased for fleets of business firms and for truckers. The description of overhead sales, given above, would apply to such sales, and the threshhold would be encountered for a large portion of such sales. Thus, much of the truncation occurs for those parts of sales that go to services and overhead expenditures.

The largest losses due to truncation, however, are for metals. We have already observed that when materials have specialized uses, the prorating procedure tends to assign them much too widely. In an analysis of the sales of lead to industrial chemicals, or of zinc to steel, the proliferation of prorating errors tends to dissipate the effect, producing many small relationships where truncation soon occurs. Metals also are frequently assigned to industries that produce repair parts which are widely (and inaccurately) dispersed by prorating their distribution by the repair sectors. The result is that a large proportion of the sales are truncated, and that what is included is generally inaccurate.

The relationship between truncation and prorating errors can be seen by the following. Consider the path products that are below the threshhold .0005 and above the threshhold .0002. For every material, at least one half of these paths represent serious prorating errors (the reader can check this by analyzing the smallest paths in Appendix C). This means that our computation went to the point where it was generating a significant proportion of "noise".

It does not follow, of course, that every path that is accurate has been computed. Two areas were identified in which small path products were eliminated by the threshhold when they should have been included. Because the industries that produce end objects (e.g., lawn mowers, appliances) and purchase small quantities of components (e.g., springs, stampings, etc.) would have many of their purchases truncated, it was arbitrarily decided to increase their steel content by 5%. This adjustment is shown in Table 4.5. Similarly, because packaging is sold widely and is likely to be truncated in a number of cases where it should not, an adjustment was made for paper and for plastics.

The path products given in Appendix C are incomplete, but the incompleteness is not large and is readily adjusted for. The incompleteness does not stem from general interdependence,* but from various small direct sales. This means that it is adequately safe to make direct adjustments of major flows, because we are not dealing with a matrix that is unstable and whose results would be significantly affected by such direct adjustments.

This result would have to be reexamined in any analysis that included overhead expenditures. Since our study is confined to the Embodied Submatrix, that is beyond our concern.

CRITIQUE OF THE INPUT-OUTPUT MODEL

Our study has shown that the input-output model cannot be used as a "black box" which automatically generates estimates of the amount and composition of solid waste. The input-output model does not provide a completed answer, but rather provides the basis for a new type of analysis. However, the abundant information contained in the model requires considerable adjustment. The original problem (how to estimate levels of solid waste) can be converted into a new problem (how to estimate the adjustments that must be made to the input-output model so as to properly allocate the flows of embodied materials).

It is worth asking whether this is an improvement. An example will illustrate what is involved. Prior to our analysis, the available estimate for glass waste was 1.0 million tons of pressed and blown glass (including some products made from purchased glass) and 0.1 million tons of flat glass.**

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*The evidence for this is analytic (the one-way nature of embodied flows) and empirical (the absence of cycles that are embodied).

**Arsen Darnay and William E. Franklin, Salvage Markets for Materials in Solid Wastes, Midwest Research Institute, Kansas City, Mo., 1972, p. 71-1.

Our analysis provides a significant expansion in the product composition of glass waste (see Table 4.3), but our estimates are taken from an input-output table which allocates glass by value. It was not possible to obtain data on the price per pound of various uses of glass, so while estimates were made of the tonnage of glass waste, they should be regarded as preliminary estimates.

Future analysts are now faced with two options: they can estimate the detailed composition directly, or they can make inquiries on the price per pound that is paid by various users. Furthermore, they can do both and test the consistency of their estimates. It would appear that the numbers in input-output models can contribute significantly to the improved accuracy of these estimates.

Future Use of This Study

An input-output table for the United States will continue to be compiled periodically. Let us consider how an analyst can take advantage of that fact in developing estimates of solid waste based upon future revisions of the table. There are at least four different ways this study could be used, involving successive degrees of difficulty.

(a) First, the Method of Minimal Adjustment can be applied mechanically to any input-output model. This would involve elimination of any industry whose entire row or column is nonembodied, and the inversion of the Embodied Submatrix. Then the ratios of adjustment, given in Appendix B could be applied to these results in order to take account of adjustments made in this study. It is assumed that the adjustments in this study are approximately applicable to future input-output models.

(b) A second approach would be to use the ratios of adjustment given in this study for any adjustments that are minor, but to re-calculate those adjustments that are more significant. The size of each adjustment is given in Tables B-3 in Appendix B.

(c) A third, and much more expensive, program would be to redo the study using a future input-output table. Such an analysis should take account of the significant adjustments and the data gaps that are identified in the present study, and should give particular attention to these difficulties. Table 4.22 lists the major data gaps and questions identified by the study.

(d) It would be possible to use the experience of the present study as a background for the design of a study that uses input-output data in a somewhat different manner.

This latter possibility requires a more extended discussion.

Another Method for Estimating the Composition of Solid Waste

The fourth method will provide a contrast with the method of the present study, and may provide guidance for a future project. The present study began with an entire input-output model, and then successively removed various coefficients. A large number were removed by eliminating the rows and columns that produced the Embodied Submatrix. Then path products were computed and studied. As further errors were uncovered, additional coefficients were removed. The final result makes use of a rather small proportion of the coefficients in the input-output table.

It would be possible, then, to proceed in the other direction--to treat the input-output table as a data source, and to select from it whatever data satisfied certain rules. The present study has identified the rules that must be satisfied:

(1) Analyze any materials that sell to other materials, to determine whether the transaction involves double weight.

(2) Avoid nonembodied inputs.

(3) Do not follow paths beyond the form in which materials are disposed of. Give special attention to packaging materials.

(4) Reject inputs for which prorating errors are possible.

The last rule will eliminate any long paths, so the computation of path products would not be difficult. One could imagine it being done without using a computer.

TABLE 4.22

DATA GAPS IDENTIFIED BY THE STUDY

1. Total weight is difficult to obtain because of double-counting within an industry. The most serious problem is steel. The estimate for weight of lumber is of unknown accuracy.

2. The assumption of prorating used when computing an input-output model, makes the results uncertain for nonferrous metals, fibers, and much of plastics. Additional information is required to provide correct flows.

3. Price per pound.
   There is no data for glass.
   For lumber, the unit is board feet, and different types of lumber call for different conversions from board feet to weight.
   For rubber, the available data by product is not readily assigned to industries of use.

4. Data for industrial waste is especially fragmentary and frequently out of date.

5. Time lags (see Chapter 5).
   Except for transportation equipment, almost no data exists on length of ownership and patterns of secondary use.
   Information is nonexistent on length of time automobiles are held for cannibalization.

The direct selection of relevant data might be more efficient than in the present study, but that is not certain. The major advantage would be flexibility. It would be possible to use the most detailed input-output table that is available, the 484 sector table provided by the Department of Commerce. It would sometimes be possible to use the "worksheets" for this table, which do not form a balanced table but which do provide even greater detail. This would make it possible to identify the sources that are used in preparing the input-output table, and to determine how these sources were used and what additional estimates were made. This would facilitate comparison with other studies of solid waste that have relied upon the same (or comparable) data sources.

Another advantage of such an approach is that it would often be possible to translate directly into physical units. The input-output table uses data on values, but the original data sources often record physical units as well. Such an approach would take advantage of the procedures and estimates that are utilized in preparing input-output tables, but would introduce physical units in the most direct manner possible.

Techniques of Criticism

The computation of path products of the input-output model permits the model to be criticized in two ways: The sequence of flows implicit in the input-output model can be compared with our knowledge of flows in an economy, and the quantities define the significance of any path: Path products provide a direct measure of sensitivity to a change in output resulting from a change in final demand or a change in a coefficient. This has been discussed in Chapter 3.

In a similar manner, this study introduces a number of techniques that permit detailed scrutiny of its own methods, and of various assumptions that may have significant effects upon the final answers. The following assistance is given the reader who wishes to question details of the analysis:

(a) Every major path product is explicitly classified as satisfying or not satisfying the assumption of prorating. (See Table B-2, Appendix B.)

(b) All path products that were computed for this analysis are given in Appendix C and sorted in three different ways. The utility of each of these sorts is discussed in the introduction to Appendix C.

(c) The size of the adjustment for each type of assumption is specified in Table B-3 of Appendix B. This information permits the user to identify the adjustments that are most significant. A critic can focus his attention upon those adjustments that have the largest impact upon the final answer.

The significance of these techniques is that the analysis can be readily verified or modified by outside experts since the assumptions and operations on which it is based are clearly visible at every step. If any adjustments are based on faulty assumptions or erroneous information, the possibility of their being identified and corrected is greatly enhanced by their explicitness. Too often, in studies of waste estimation, finished estimates are provided without explanation--the products of a "black box" methodology. EPA has much to gain, however, from studies whose assumptions and methods are explicitly identified. Such studies permit criticism in depth, permitting a faster identification of points of disagreement--and consequently a faster convergence toward estimates that take into account the widest possible range of relevant considerations. In the present study, those estimates that survive such criticism can be considered as accurate as our collective knowledge will permit.

It would be desirable for other studies to use techniques of explicitness that are comparable to those of this study. Further, it may be essential for EPA to have an office that can assist in the collection of detailed criticism of studies and in the adjudication of differences. This office can then maintain updated versions of the estimates that are the most widely accepted. An important role for the SEAS model, developed in EPA, would appear to be to retain and use the detailed information that survives criticism in a wide range of aspects of an economy.

Needed Improvements in Input-Output Tables

The adjustments required for this study provide an implicit criticism of the input-output model. These adjustments can be divided into two types:

(a) Those that arise because of special aspects of the present study, and

(b) More general adjustments that would be advocated for any use of the input-output model.

The first group of adjustments do not constitute a critique of the input-output model since they are necessitated by the use of this model to do things it was not originally designed to do. This group included the following adjustments:

(1) Removal of double weight
(2) Elimination of nonembodied inputs
(3) Adjustment for industrial waste
(4) Shifting materials to account for the pattern of disposal

Aggregation errors are different. They represent the fact that *the model is inaccurate for any use of the input-output model*. The purpose of the model, surely, is to represent the structural dependence between final demand and production, or between value added and prices. To do this, the model assumes that inputs are complements. Whenever inputs are alternatives which can be used in place of one another, or whenever there are industries consisting of diverse parts that use very different inputs, then the assumptions of the model are violated. Many examples of each of these were found in the input-output table used in this study.

It might be thought that disaggregated input-output tables would avoid aggregation errors. Table 4.23 shows the number of sectors in various input-output tables for the U. S. The most detailed table has over 2-1/2 times as many sectors as the table used in this study. It does avoid some problems. For example, it disaggregates Miscellaneous Textiles into the separate sectors shown in Table 4.8, and therefore avoids errors pertaining to the allocations of fabrics to tires.

Table 4.23

Number of Sectors in Various Input-Output Tables for the U. S.

	Number of Sectors	Date of Table
Bureau of Labor Statistics	129	1970
INFORUM (used in this study)	182	1971
Largest Published Table*	367	1967
Largest Balanced Table**	484	1967

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*U. S. Department of Commerce, Bureau of Economic Analysis, Input-Output Structure of the U. S. Economy: 1967, 3 Volumes, 1974.

**Prepared by the Bureau of Economic Analysis and available on tape.

The largest errors in our analysis, however, were for fabric mills [35] and the sectors that process metals, shown in Table 4.16. Another sector that accounts for serious aggregation errors, but which was not discussed in this study, is Industrial Chemicals [55]. Table 4.24 shows the level of detail for these sectors in the most detailed available input-output table. There is slight disaggregation of the sectors that account for the major prorating errors, and the disaggregation that occurs does little to eliminate errors. Furthermore, there is no use of process sectors which would by-pass errors by assigning flows directly to the using sectors.

Evidently, prorating errors have not been of great concern to data collectors because there has been no visible attempt to disaggregate those sectors that cause the most difficulty. Hopefully, this study will make clear to the Commerce Department, which compiles the official table, that major prorating errors should be eliminated from the base table. Until that is done, major users of input-output, such as EPA in its SEAS model, are undertaking the task of eliminating prorating errors where it affects their uses of the model.

The use of values rather than physical units is a different problem. Our study finds that the adjustment required to remove prices is larger than the amount of indeterminancy that arises from prorating. However, there are some uses of input-output for which values are more appropriate than physical units. The input-output model is used to "complete" the National Accounts, and for this, values are required. Some inputs, such as wages and overhead expenditures, may be more accurately reflected by value of shipments than by physical units. Embodied inputs, when they do not encounter prorating errors, are more accurately represented by physical units. For example, the iron ore used for steel is more accurately predicted by the tonnage of steel, and the chromium (used in significant quantity in stainless steel) is not accurately predicted by either tonnage or value of steel. It is apparent that existing models are distorting the functional dependence, but the solution appears to be rather complex. The theory needs to be extended at this point.

TABLE 4.24
CLASSIFICATION OF LARGEST INPUT-OUTPUT TABLE FOR SECTORS CAUSING PRORATING ERRORS

SECTORS IN THIS STUDY			COMMERCE SECTORS		
Industry Number	Industry Name	SIC	Industry Number *	Industry Name	SIC
35	Broad and narrow fabrics		160100	Broadwoven fabric mills & fabric finishing plants	
			160200	Narrow fabric mills	
			160300	Yarn mills & finishing of textiles, n.e.c.	
55	Industrial chemicals	281**	270100	Industrial inorganic & organic chemicals	281**
88	Primary nonferrous metals, n.e.c.	3339	380600	Primary nonferrous metals, n.e.c.	3339
89	Nonferrous rolling & drawing n.e.c.	3356	380900	Nonferrous rolling & drawing, n.e.c.	3356
90	Nonferrous wire drawing & insulating	3357	381000	Nonferrous wire drawing & insulating	3357
91	Nonferrous castings & forgings	3369	381300	Nonferrous castings, n.e.c.	3369
		3392	381400	Nonferrous forgings	3392
92	Metal cans	3411	390100	Metal cans	3411
94	Plumbing and heating equipment	3431	400100	Metal sanitary ware	3431
		3432	400200	Plumbing fittings & brass goods	3432
		3433	400300	Heating equipment, except electric	3433
95	Structural metal products	3441	400400	Fabricated structural steel	3441
		3442	400500	Metal doors, sash, & trim	3442
		3443	400600	Fabricated plate work (boiler shops)	3443
		3444	400700	Sheet metal work	3444
		3446	400800	Architectural metal work	3446
		3449	400900	Miscellaneous metal work	3449
96	Screw machine products	3450	410100	Screw machine products & bolts, nuts, rivets & washers	3450
97	Metal stampings	3461	410200	Metal stampings	3461
98	Cutlery, hand tools and hardware	3421	420100	Cutlery	3421
		3432	420201	Hand & edge tools, n.e.c.	3423
		3425	420202	Hand saws & saw blades	3425
		3429	420300	Hardware, n.e.c.	3429
100	Valves, pipe fittings, and fabricated pipe	3494 3498	420800	Pipe, valves & pipe fittings	3494 3498
101	Other Fabricated Metal Producst, n.e.c.	3471	420401	Plating & polishing	3471
		3479	420402	Metal coating & allied services	3479
		3492	420600	Safes & vaults	3492
		3493	420700	Steel springs	3493
		3496	420900	Collapsible tubes	3496
		3497	421000	Metal foil & leaf	3497
		3499	421100	Fabricated metal products, n.e.c.	3499
102	Engines and Turbines	3511	430100	Steam engines & turbines	3511
		3519	430200	Internal combustion engines, n.e.c.	3519

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*The last two digits represent disaggregation of some of the 380 sectors into 484 sectors. When these digits are "00", the sector has not been further disaggregated in the 484 order table.

**Omits 28195 Alumina

The other difficulties met in this study, and listed on previous pages, are not the responsibility of those who construct input-output models. Nevertheless they present important new opportunities since there are undoubtedly many uses of a submatrix of embodied inputs. It is well within the charter of input-output for the official table to classify each input as embodied or not, permitting a computer to separate them. It is within the charter of a general-purpose table for it to identify and eliminate cases of double weight. It would be a proper addition to available data for the input-output table to attempt to estimate industrial waste in physical units, rather than merely using the monetary data given in the Census of Manufactures. The only adjustment that appers to be of limited generality is the identification of the pattern of disposal. This seems almost solely the concern of those who study solid waste.

Until the Commerce Department seizes these opportunities to provide useful data, however, EPA will be required to make such adjustments itself if it is to utilize the input-output model in its analysis of the composition of solid waste.

It is possible to end the critique on a positive note. The input-output model is an excellent model for the very reason that it looks weak. Its strength is that it can be criticized in depth, and thereby improved. The model can represent technology at a sufficient level of detail to make possible the identification of errors, and its level of detail can be extended (as necessary) so as to correct these errors. The corrected model is also an input-output model, since the basic mathematical structure has not changed. This mathematical structure provides a bridge between detailed knowledge concerning specific materials and macroeconomic information on productivity and disposable income.

The next chapter will discuss some of the reasons why other techniques used by economists are not subject to such criticism and, therefore, cannot achieve the same level of accuracy that can eventually be achieved by input-output models.

New Instructions to Data Collectors

It has been pointed out that the input-output model can be viewed as reflecting a set of instructions that are given to a government agency telling it how to organize data. The instructions of the input-output model are concerned with an accounting process by which every number is estimated twice and the separate estimates are reconciled. The only instructions concerning classification are that a fixed set of categories be identified in advance.

Our analysis shows that additional instructions are needed for the process of classification. We have added the instruction that the flows generated from the model should represent flows in the economy, and that the classification of the model should be adjusted so as to permit this. It must be recognized, however, that there is an inherent incompatability between the requirement that a table represent an entire economy and the requirement that the flows derived from it be entirely accurate. The rule of accounting says that every part of the economy must be included in some sector. The rule of accuracy of flows asks that no sector include deviant and unusual cases. The extreme variability of modern economies insures that the two rules will generally be in conflict.

The accounting rule--that the entire economy be included in the table--must be pre-eminent which means that the flows can never be perfectly accurate. The more significant paths can be corrected, but it is as impossible to correct all paths as it is to compute them all. This means that some answers will be more accurate than others in any input-output model. It follows that when the model is utilized in new ways, it will almost always be desirable to make some adjustments in order to improve the accuracy of additional parts of the model. To illustrate, during the construction of SEAS, the first adjustments were made to provide accurate estimates of pollutants, and when the model also emphasized resources (fuels, minerals and metals), then additional adjustments had to be made to improve the accuracy of the model in these areas.

The adjustments that are made to the model generally depend upon technological information. The problem faced by economists is not that too little is known about technology, but rather that too much is known. The problem facing economists is not how to discover the truths concerning technology, but is how to select the information that is of relevance for economic analysis. The criterion of section is that the information result in significant differences at the level at which economic problems are analyzed. Technological economics does not require laboratories, but does require mathematical techniques for identifying significance.

Two types of significance need to be distinguished: (a) significance as shown by a model and (b) significance as shown by departures from the model. An illustration of the first is the computation of path products, which can be sorted by the size of the path product. (This is done in Appendix C.) The sorting identifies which paths have the largest effect upon the answer as stated by the model. The search for errors can be confined to the larger effects.

The second type of significance is illustrated by the large variation in price per pound that is paid for various materials. The differences are so large that, in many cases, more of the cost of a material is unaccounted for than is accounted for by the model. The cost of knives and forks, for example, cannot be accounted for by the iron ore that is required for them. Some other inputs, considerably more expensive than the iron ore, account for a major portion of the cost. Such differences warn the data analyst that there is something significant that is not explained by his present model. Through such analysis, the data analyst uncovers aspects of technological information that are essential for accuracy of the analysis. Examples of other ratios that might be similarly instructive are man-hours per output and energy input per output. Ultimately, it would be desirable to compute such ratios on a plant-by-plant basis, and to use the results to determine the suitability of grouping plants by Standard Industrial Classification.*

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* For a criticism of fixed categories and a suggestion that statistical analysis be used to reclassify continually, see Stafford Beer, Decision & Control, New York, John Wiley & Sons, 1966, Chapter 13.

To summarize, the data collector can be given four rules:

- Rule 1: Balance the accounts of transactions in an economy. Form coefficients.
- Rule 2: Compute the path products and arrange according to the proportion of output each accounts for.
- Rule 3: Appraise the accuracy of flow of the more significant paths, correcting those that require it.
- Rule 4: Compute the variation of a large number of ratios, explain any large discrepancies, and extend the functional dependence in the model as required.

Rule 1 is presently used. Rules 2, 3, and 4 are given here for the first time and are not part of the standard practice of those who construct input-output tables.

CHAPTER 5

PROJECTIONS OF HOUSEHOLD SOLID WASTE

This chapter provides projections of the expenditures that account for the generation of household solid waste. These expenditures are expressed in three categories of projections: personal consumption expenditures, coefficients of inter-industry sales, and such macro variables as disposable income.

A major task of this study was to review various forecasting models that are available to appraise them, and to select one with which to provide projections of future levels of household solid waste. Accordingly, the INFORUM model [1,2] developed at the University of Maryland was selected for the study. This chapter will not attempt a complete description of INFORUM, but will review a number of important aspects of the model including the basis for its selection as an appropriate means of projecting consumer expenditures.

An important objective of this chapter is to provide a critical appraisal of the methods of projection currently used by economists. EPA is now in the vanguard of a major revision and extension of the techniques of economic analysis, and a critique at this time could prove to be of critical importance in guiding future EPA work in which such techniques are to be used.

PROJECTIONS OF PERSONAL CONSUMPTION EXPENDITURES (PCE)

A technique widely used by economists is the econometric technique which consists of three steps:

(a) Obtain various categories of data in time series;

(b) Define a theoretical dependence between these time series which is expressed in terms of functional equations with certain parameters that are not yet specified;

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[1] Almon, Clopper Jr., Margaret B. Buckler, Lawrence M. Horwitz and Thomas C. Reimbold, 1985: Interindustry Forecasts of the American Economy, Lexington, Mass., D. C. Heath and Co., 1974.

[2] Almon, Clopper Jr., The American Economy to 1975, New York, Harper and Row, 1966.

(c) Estimate the best fit of the parameters that result from fitting the time series to the equations.

The data source for the time series of personal consumption expenditure is the Census of Manufactures. The Commerce Department converts data from the Census into a time series, published in the Survey of Current Business*, and this time series is used by the well-known projections of Houthakker and Taylor.[3] The authors of INFORUM** give some sophisticated criticisms of this data, and construct their own time series from the Annual Census of Manufactures.

Economic theory indicates that consumer expenditure will depend upon income and price. The equations of econometric models generally use various forms of these variables, along with such other variables as rates of unemployment, interest rates (for commodities purchased on credit), the stock of durables, etc.

The Method of Projection Used in INFORUM

In order to obtain a closer look at the methods that are involved, it will be useful to examine how projections of personal consumption expenditure (PCE) were obtained for INFORUM. A time series of personal consumption expenditure was obtained for each year from 1958 to 1971. Part of this data, for the years from 1958 to 1964, was used to estimate coefficients. These in turn were used to "predict" expenditures for the years 1965 to 1971 which could then be compared with the actual expenditures for these years.

Two types of equations were used. In one type, expenditures lag behind increases in income to account for the acquisition of new spending habits (as with coffee or tobacco), or upon equipment that must be purchased (as with insurance or motor vehicle repair). The other type of equation permits expenditures to over-respond when there were changes in income, since these changes affect the ability of consumers to purchase on credit. Cross-section data on the differences in expenditures by different income groups was also used. Finally, the coefficients providing the best fit for 1965 to 1971 were computed.

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*Published in the July issue each year as part of the National Income statistics.

**See Almon et al, Reference 1, pp. 25 ff.

[3] Houthakker, H. S., and Lester Taylor, Consumer Demand in the United States: Analyses and Projections, Cambridge, Mass., Harvard University Press, 1970.

In this way, four different equations and projections were obtained for each category of consumer expenditure. The various estimates were then compared and the estimate was selected that was judged to be most accurate. For some categories of consumer expenditure, no one of these four statistical approaches provided an estimate that was felt to be acceptable, so an equation was "made up" that was consistent with the values obtained for similar categories of expenditure.*

Ultimately, then, the coefficients used were obtained as judgments. Nonetheless, the method is "empirical" in the sense that considerable empirical evidence was compiled and statistical results were computed and analyzed. It did not use results that were obtained mechanically from data, however.

The method used in INFORUM is somewhat more arbitrary than is usual, but it illustrates some general characteristics of all econometric analysis:

(a) Economic theory does not define a unique set of applicable equations, so various equations can be used.

(b) There are many different ways to measure economic phenomena, and while some of these are more complete and more respected than others, none of them is indisputably the "correct" way to measure.

(c) There would be wide agreement among economists as to the approximate values to expect for coefficients. Econometricians do not publish and use coefficients that violate their *a priori* sense of the correct sign of dependence and the approximate range of coefficients. They utilize other data or attempt other explanations until they are satisfied with their results.

(d) The data available to economists includes the significant effects that result from idiosyncratic events that are not readily included in the equations. Examples are strikes, embargoes, and wars.

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*Taken from Almon, et al, Reference 1, p. 39.

As supportive evidence, we note that an in-house study by Jack Faucett Associates[4] used the equations of Houthakker and Taylor, but applied these equations for more recent years. Of the 82 commodity time series, it was found necessary to ignore the equations for 14 commodities and to make substantial adjustment for 34 additional commodities. Adjustments had to be made, for example, for Domestic Service, Motion Picture Theaters, Jewelry, and Barbershops, each of which has been affected by variables other than income and price, i.e., by competition with new products or by changes in social attitudes.

Projections of Consumer Expenditure: Results of the Study

Personal consumption expenditure depends upon variables that have yet to be discussed--disposable income and relative prices. The equations of personal consumption expenditure define the differential growth by type of expenditure; so it will be useful to examine the projections of the study before discussing how the independent variables are forecast. Appendix D, Table D-1, gives the projections of all types of personal consumption expenditure. Some of these do not affect our present study because they represent services which do not generate household solid waste. Our concern is with sectors 21 through 150, and the most striking result is that most of them increase at a similar rate (slightly less than two-fold from 1971 to 1985). The small number of categories of expenditures that grow most sharply are shown in Table 5.1. These are almost all durables and are largely made of metal, so the proportion of metal in household waste can be expected to grow in the future.

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[4] Jack Faucett Associates, Inc., "Long Range Projections of Personal Consumption Expenditures", Final Report #JACKFAU-73-104-1, August, 1973.

TABLE 5.1

CATEGORIES OF PERSONAL CONSUMER EXPENDITURE PROJECTED TO INCREASE MOST SIGNIFICANTLY FROM 1971 TO 1985

SECTOR	INDUSTRY	PROPORTION OF INCREASE 1971 TO 1985
134	AIRCRAFT	7.5
127	COMMUNICATION EQUIPMENT	3.6
22	OTHER ORDNANCE (GUNS)	3.4
106	MACHINE TOOLS, METAL CUTTING	3.1
115	OTHER OFFICE MACHINERY	3.1
117	MACHINE SHOP PRODUCTS	3.0
145	PHOTOGRAPHIC EQUIPMENT	2.9
122	WELDING APPARATUS AND GRAPHITE PRODUCTS	2.9
146	WATCHES, CLOCKS AND PARTS	2.7
60	PESTICIDES AND OTHER AGRICULTURAL CHEMICALS	2.7
120	MOTORS AND GENERATORS	2.7
101	OTHER FABRICATED METAL PRODUCTS NEC	2.6
97	METAL STAMPINGS	2.5
95	STRUCTURAL METAL PRODUCTS	2.5

Critique of the Projections of Personal Consumption Expenditure

The projections of PCE illustrate the advances in econometrics that have been made in economics in recent decades. Econometrics combines economic data, statistical techniques, and economic theory in order to provide projections of economic variables. While the progress in this approach has been considerable, the foregoing discussion reveals some limitations of the present state of economic forecasts.

First, the level of detail in the models does not come near the level of detail at which economic relationships are analyzed. For example, the projections use a term "change of income," which is measured in the aggregate. This measure ignores the difference between entry into the work force of a small number of people previously excluded as opposed to a small increase in income for a large number of people. These could be expected to result in very different patterns of expenditure and increased credit purchases. Similarly, the different ways in which a tax rebate can be implemented involve very different redistributions of income, and the effects of those differences cannot be analyzed adequately with the aggregated data that are used in INFORUM or by Houthakker and Taylor.

Our second criticism is that the analysis provides no method of permitting the reader to see the implications of any special knowledge that he might possess. The difficulty is that econometrics is too much of a "black box". The authors of INFORUM have shown some of the structure of the box by comparing several different forms of equations, and by showing how well the different equations predict for various years. They also require that their results be economically reasonable and they are willing to revise estimates that appear to be questionable. However, the statistical methods used in econometrics have not been subjected to the dissection that has been applied to the input-output model in Chapters 3 and 4 above. This means that it is not possible for the reader of an econometric study to use his knowledge of the economy in order to appraise the acceptability of the mathematical operations that are made. Since mispredictions by "black box" methods are only discovered after they no longer matter, there is a need for more immediate methods of appraisal.

Econometrics is a form of induction, and the fundamental assumption of induction is that various periods are similar -- that the differences between them are explained by the variables in the equations. Econometric analyses generally omit World War II because this period is "different," but they do not seek help in identifying other periods that are sufficiently unusual as to require omission from the analysis. Econometric projections would deserve more trust to the extent that they spell out the basic assumptions of induction in such a manner that anyone with special knowledge could identify and correct errors. What is called for is the development of methods of computation and display that would identify the relevance of idiosyncracies of specific years. Then the analysis of time series would permit a dissection comparable to what the method of paths provides for matrices.

PROJECTIONS OF THE ENTIRE ECONOMY

Personal consumption expenditures depend upon disposable income and relative prices so projections of these variables are required. Disposable income and relative prices may depend upon other variables, which in turn, may depend upon still others. It is possible to encounter an infinite regress of dependence: for example, disposable income depends (in part) upon the production levels of industries, and this depends (in part) upon personal consumption expenditure which -- we have seen -- depends upon disposable income.

Two methods can be used to deal with this kind of interdependence. One method is to construct a set of equations that are simultaneous--that represent the mutual dependence-- and then to extrapolate all of the variables at once while taking account of the interdependence between them. The other method is to identify certain variables that can be viewed as being relatively independent of economic forces and that are readily predicted.

When projections are short-run (up to about five years), emphasis is placed upon the adequacy of demand. We have already seen that this involves simultaneous dependence: demand affects production, which affects income, which affects demand. In long-run projections (five years or more), this difficulty can be side-stepped by assuming that the government will attempt to eliminate large-scale unemployment. If demand is so low that there is major unemployment, the government will increase its expenditure or reduce its tax levels. This may not be effective immediately, but after a number of years the economy will respond. This means that in the long-run the level of disposable income will be defined by the number of people available and desiring to work. This is called a "supply" analysis, since the level of economic activity depend upon the supply of people seeking employment.

Since our concern is with estimates up to 1985, the question of supply analysis is of particular interest. It involves the following steps:[5, 6]

(a) Estimate the number of people in the U.S. of working age.

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[5] "The United States Economy in 1985", articles by Jack Alterman, Denis F. Johnston, Neal H. Rosenthal, and Ronald E. Kutscher, Monthly Labor Review, December, 1973, pp. 3-42.

6 U. S., Bureau of Labor Statistics, The Structure of the U. S. Economy in 1980 and 1985, Bulletin 1831, Washington, D. C., Government Printing Office, 1975.

(b) Estimate the proportion of these that wish to be employed.

(c) Adjust for the normal rate of unemployment.

(d) Estimate the average wage per person in the future.

These estimates in turn depend upon other estimates, and the entire analysis is summarized in Figure 5.1.

The least difficult estimate is the number of people of working age. In a projection to 1985, all possible people have already been born, so the only variation comes from death rates. The analysis lags the age of the present population, adjusting for death rates and migration. Death rates are low and very stable. Emigration has been low and immigration into the U. S. is restricted.

An estimate of the desire to work involves greater uncertainty. Historically, most men have wished to work, but the attitude of women of all ages towards employment has become difficult to predict. There may also be changes in attitudes toward employment on the part of young men (younger than 25) and old men (older than 60). There is the possibility that rising affluence will increase the number of people at all ages that do not work, or who work intermittently.

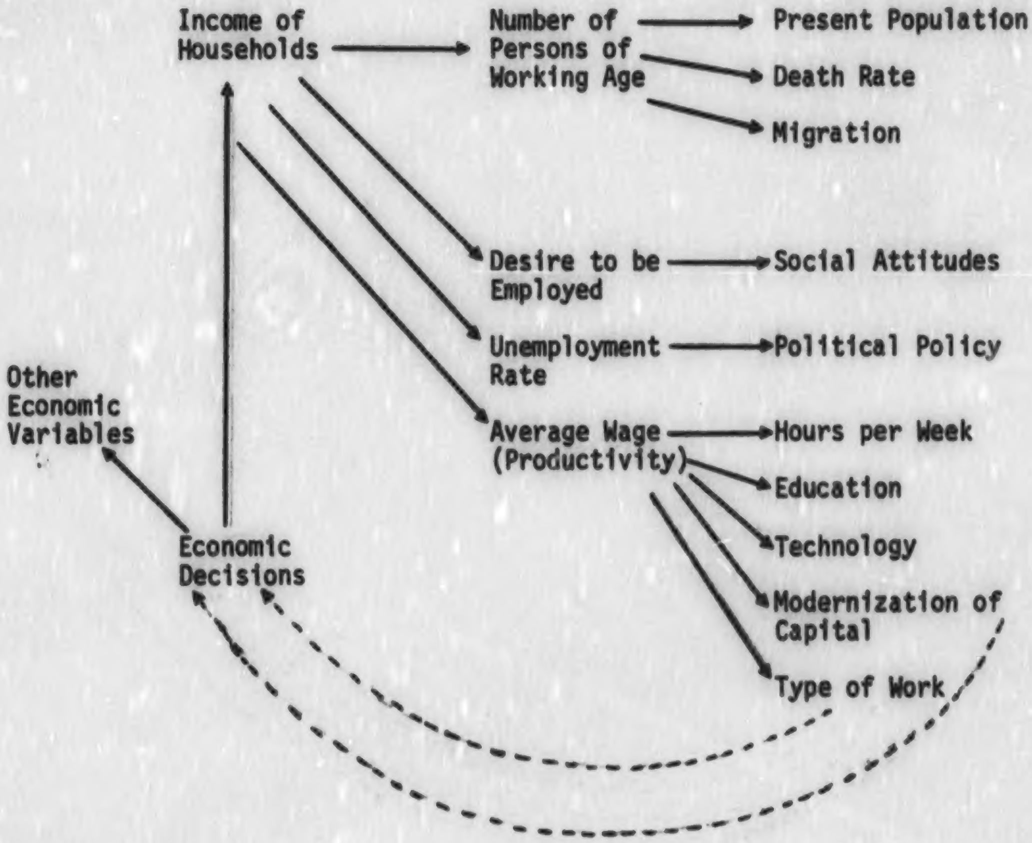
An adjustment must be made for the unemployment rate because there are always some people between jobs or seeking work, even under what is called "full" employment. This ratio is generally taken to be 4% and during times approximating full employment, it does not vary widely from that figure.

The last factor, the average wage, is the most problematical. What is needed is a prediction not of the average monetary wage but of the average "real" wage (we are not predicting the future wage level, but are concerned with the amount of work that can be accomplished). After all, if we assume that the government will maintain full employment by increasing demand, then we need to know the quantity of demand that the total labor force is able to produce. Hence we need to know the average productivity of the workers in the U. S.

Figure 5.1 shows that average productivity depends upon aspects of the economy which themselves depend upon the level of personal consumption expenditure. Some projections ignore this interdependence and project

Figure 5.1

DEPENDENCIES FOR PROJECTING INCOME OF HOUSEHOLDS


Income of Households
Number of Persons of Working Age
Present Population
Death Rate
Migration
Desire to be Employed
Social Attitudes
Unemployment Rate
Political Policy
Average Wage (Productivity)
Hours per Week
Education
Technology
Modernization of Capital
Type of Work
Other Economic Variables
Economic Decisions

productivity as a single, average quantity. Other projections take account of the interdependence, as is discussed below.

Relative prices also affect personal consumption expenditures, so it would be desirable to have predictions of relative prices. There is less agreement by economists as to how to predict these in the distant future. In long-run models, relative prices are projected in very different ways in different models.

Levels of Interdependence

We have considered analyses at two levels of aggregation. The projections discussed above relate to the entire economy so they can be referred to as "macro" projections. The input-output model operates at a more detailed level (a "micro" level) of commodities and services. Chapter 2 shows the relationship between these two levels. The input-output model is based upon a set of balanced accounts at the detailed level, and it provides a model for part of these accounts. It assumes that final demand and value added are projected independently of the input-output model. The macro analysis provides projections but it only provides the total levels of final demand by type and value added by type. For example, the macro projections provide for total expenditure by the federal government. The input-output model requires the commodity detail that is implied by this expenditure--that is, federal purchase of motor vehicles, writing paper, etc.

The two levels are depicted in Figure 5.2, where the input-output model represents part of the economy, while the macro projections provide totals for the remainder of the economy. The two areas marked with question marks in Figure 5.2 identify the point of interface between the two analyses. In particular, expenditures of various kinds need to be reallocated into the detailed commodities that are required. Furthermore, to the extent that they are relevant, detailed estimates of the components of value added are also required. In particular, since our analysis of total demand is dependent upon an estimate of productivity, then our macro estimate of productivity could be checked against the sum of detailed estimates.

We have already seen, in the analysis of personal consumption expenditure, how projections can be made that fill in some of the question marks. A time series is obtained for each of the cells (e.g., personal consumption expenditure for paper products), equations are specified with undefined

FIGURE 5.2

RELATIONSHIP BETWEEN MACRO PROJECTIONS AND THE INPUT-OUTPUT MODEL

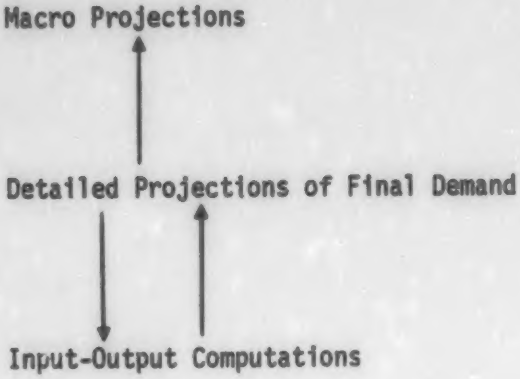
	Accounts		Totals
Accounts	Input-Output Table and Model	Final Demand by Sector Detail	Total Output (Computed by Input-Output Model)
	Value Added by Sector	Can be Ignored	Total Final Demand (Projected by Macro Analysis)
Totals	Total Output (Computed by Input-Output Model)	Projected by Macro Analysis	

parameters, and the parameters are estimated. These equations can depend upon the variables that are projected in the macro projections, or they can depend upon industry levels that are computed by the input-output model. Either way, the input-output computations depend upon the detailed projections of final demand (as defined by various equations), and ultimately upon the macro projections as is shown in Figure 5.3.

Such an extension of the input-output model is called a "closed input-output model." It is a system of equations that represent the entire set of accounts. These equations use the assumptions of the input-output model for part of the economy, and more elaborate equations for the remainder of the economy.

Figure 5.3

DEPENDENCE OF INPUT-OUTPUT UPON MACRO PROJECTIONS


Macro Projections
Detailed Projections of Final Demand
Input-Output Computations

The Selection of INFORUM

Once an econometric model is constructed, it can be checked against new data each year. A number of organizations find that they can pay for the activity of constructing, testing and improving such models by selling the service of making projections. Table 5.2 lists the salient properties of the services that are best known for making long-range forecasts based upon econometric models.

For the purpose of this study, the best two systems are INFORUM and the Interagency Growth Model. INFORUM has the following advantages:

(1) It is a central part of SEAS, which is the long-range forecasting model constructed by EPA.

(2) It is available without cost for studies supported by EPA. Most of these systems are proprietary and must be purchased if they are to be used.

(3) Table 5.2 shows that INFORUM has the most detailed input-output table and categories of personal consumption expenditures.

(4) The input-output table in INFORUM is 'purified',* whereas the table used by the Interagency Growth Model is not. An input-output table that is not purified has considerably more aggregation errors than has a purified table.

(5) The analysis of productivity in INFORUM takes account of the interdependence that is described as possible in figure 5.1.

(6) INFORUM is programmed in such a manner that it readily permits changes in its assumptions. This means that changes in the projections of final demand were possible for this study, and it also means that INFORUM can be used for analysis of contingencies.

The Interagency Growth Model has several advantages:

(1) It is the only system that is free to any user since it is developed by a government agency (the Bureau of Labor Statistics.)

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*For a definition of purification, see Almon et al, Reference 1 pp. 151-152.

Table 5.2

COMPARISON OF VARIOUS SYSTEMS OF ECONOMIC PROJECTIONS

Name of Model	Dimensions of P.C.E.	Dimensions of Input-Output Table
Interagency Growth Model*	82	129
INFORUM**	133	182
Chase-Econometrics[7]	Uses INFORUM	
Wharton[8]	11	50

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* Described in Reference 6.

** Described in Reference 1.

[7] Evans, Michael, *Macro Economic Activity*, New York, Harper and Row, 1969.

[8] Preston, Ross, *The Wharton Annual and Industry Forecasting Model*, Philadelphia, University of Pennsylvania, 1972.

(2) Its estimates are the official long-run estimates of the U.S. government. In particular, SEAS uses the GNP estimates of the Interagency Growth Model. It also uses INFORUM and takes advantage of the latter's capability to permit changed assumptions. The present study uses the identical procedures.

Figure 5.4 shows the projections of GNP to 1985 as made by the various econometric systems. It can be seen that the projection by INFORUM is distinctly lower than any other projection. These various econometric systems all depend upon a number of common estimates. They all use the Series E estimates of population by the Census Bureau.[9] They all use the estimates of working force and labor force participation rates as provided by the Bureau of Labor Statistics.[*] The level of unemployment is assumed to be 4%. The differences in their estimates come from their assumptions regarding the projected level of productivity.

The Projection of Productivity in INFORUM

In making their projection of productivity, the authors of INFORUM use an approach similar to that used in projecting personal consumption expenditures. Time series are obtained on the productivity of each sector from 1952 to 1971.[**] Various types of equations were used in an attempt to take account of various theoretical concepts, but when the data did not fit, these theories were ignored. They eventually relied upon five different types of equations. The main variable in these equations was calendar time or a time-like variable: the average installation date of the capital equipment in the industry. Other variables in the equations were output or its rate of change--each partially adjusts for changes in the business cycle.

Each time series was fitted for each equation using the data through 1966. Then predictions for 1967-71 were compared with the actual levels

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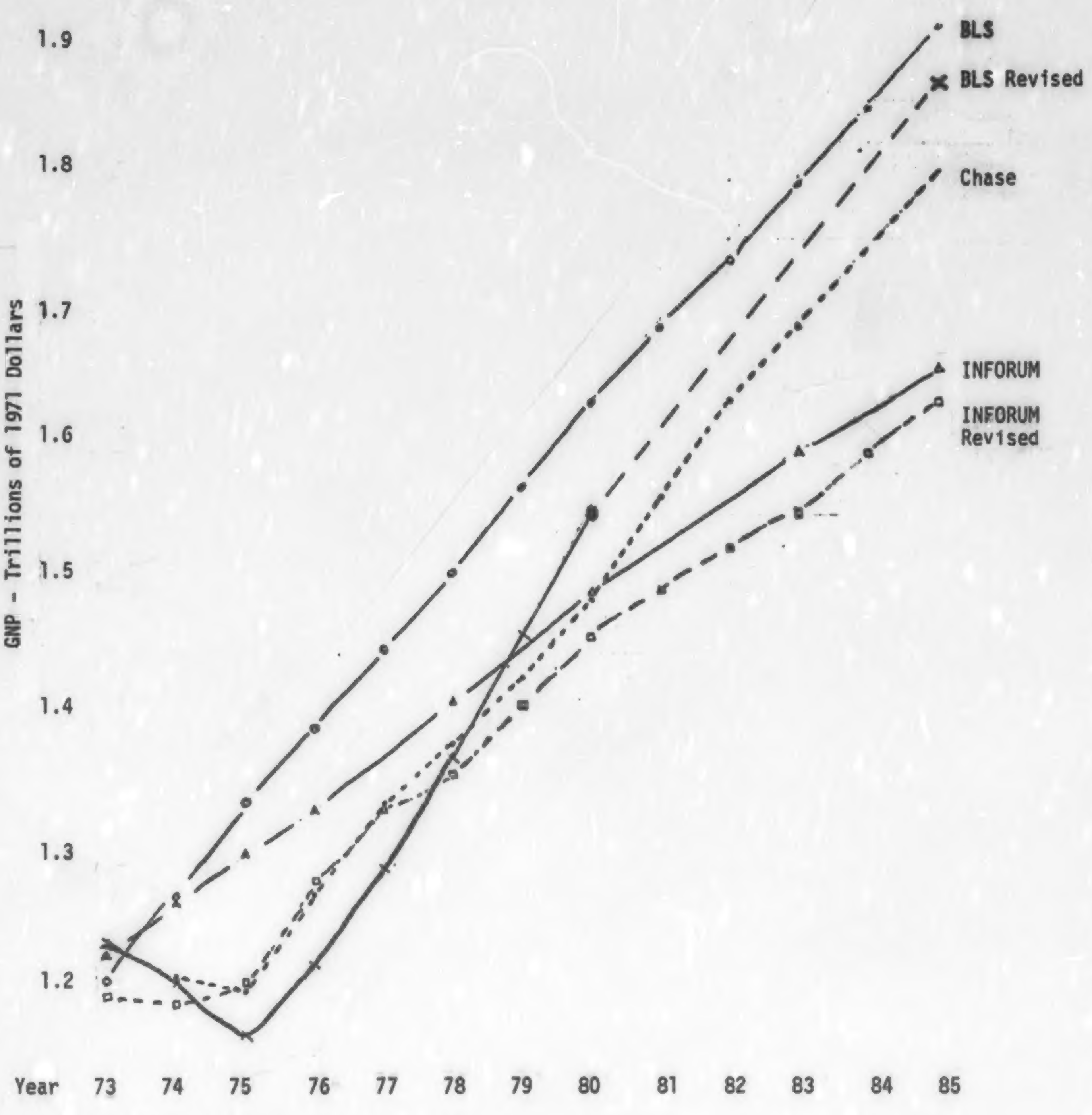
[*] References 5 and 6.

[**] The sectors were combined into 89 sectors. In some cases, data could not be obtained prior to 1958.

[9] U. S. Bureau of the Census, "Illustrative Population Projections for the United States: The Demographic Effects of Alternative Paths to Zero Growth," Current Population Reports, Population Estimates and Projections, Series P-25, No. 480, Bureau of the Census, 1972.

Figure 5.4
VARIOUS PROJECTIONS OF GNP



Compiled by Philip Patterson, formerly of E.P.A.
Revisions were made in 1975.

for these years. With this data, the equations with the smallest average error were computed and the results appraised. Although the authors generally chose the equation which gave the smallest average error, there were 15 cases in which different equations were chosen on the basis of judgment. A mechanical procedure always defined the coefficients that were used, but since there was a choice of possible equations, judgment was used to select the equation (and hence, the projected values.)

The results obtained indicate that there will be a slowing down of the rate of productivity for two reasons:

(a) Changes in the pattern of final demand and in coefficients within the matrix (discussed below) result in an increasing shift towards services which have a lower rate of productivity growth than other parts of the economy.

(b) Labor has been increasing its productivity, but at an increasingly slower rate in many industries. INFORUM projects that this slowing of the increase in productivity will continue.

We have already seen that other forecasters are not as pessimistic as INFORUM in their estimates of future levels of productivity (and hence of GNP). The results obtained by INFORUM should be examined point by point, beginning with the slowing of productivity. This in turn can be broken into two areas--manufacturing and the services.

Is there a slowing in the rate of productivity in manufacturing? This depends upon the pattern of productivity for different decades. The increase in productivity in the 1960's has not been matched in the early 1970's, but it is not certain whether the 1980's will represent a society that is "ageing" (as suggested by the authors of INFORUM) or rather a return to the increases of the 1960's. This cannot be determined solely by studying trends of data on productivity. It is also necessary to consider changes in technology that are being developed and promoted, and the rates at which they might be accepted by U. S. industry.

In projecting the productivity of services, we encounter the more fundamental problem of determining how such productivity is measured. Productivity is employment divided by output (where employment is the number of man-hours), and output should be defined by a physical unit that is invariant over time.

Often it is difficult to find such a physical unit. For example, the automobiles produced in 1960 are not precisely comparable to the automobiles produced in 1974. For purposes of measuring productivity, however, a brand of automobile (Ford) is treated as invariant over time. Since the newer cars are more complex and more difficult to produce, and since the measurement of productivity does not take account of this increased complexity, then productivity as measured increases less than it would if an adjustment were made for the increases in complexity.

The measurement of productivity is most accurate for materials that are homogeneous. There is a considerable bias in the measurement of productivity for manufactured objects, but the measurement becomes much more difficult for services where physical units are least readily defined. As an example, how does one measure the productivity of doctors giving annual check-ups? The measurement of productivity depends upon the definition of output that is used. Let us consider two possible measures of medical care: time spent in a doctor's office versus information gained concerning the state of the patient's health. Advances in medical techniques permit an increasing number of diagnostic tests to be made in a short time. Hence, a growing number of people are employed in support of 15 minute visits to the doctor. According to this measure, the productivity of the medical profession is declining over time. If the unit of output is information gained, then the improvements in medical technique are increasing dramatically because of increases in the accuracy of information as well as in the ease with which information is obtained. According to this measure of output, the productivity of the medical profession is improving very rapidly.

Economic analysis uses the first measure of output of the medical profession -- the time spent in the doctor's office -- and then speaks of slight changes in productivity in this industry. In their discussion of productivity, Almon et al have been favorably impressed with the results of such measurements.

Another possible way to analyze the productivity of the services is to consider the average wage and skill of the employees. This approach implies that higher paid employees are more productive than lower-paid ones. By this criterion, the service jobs can be divided into two types. One type of service is to provide information to the purchaser, and in this category we find a sharp increase in the average salary paid. Services of this type include those provided by doctors, professors, consultants, and financial advisors. These services are expanding at the same time that salaries have been rising. The second type of service brings specialized skills or equipment to the performance of a task, the principal product of which is neither a material product nor a form of information. This category includes retail trade, banking, airlines, and telephones. Increasing automation in these industries is permitting several possible solutions. In some cases, there are sharp increases in productivity. In other cases, this automation is permitting the use of manpower that is less skilled and less well paid.

There is another difference between the two types of services. When the service provides information, demand is elastic; it grows faster than improvements in productivity, and there is an increase in highly paid personnel and the support staff they require. In the second (task-performance) category of services, improvements in technology have permitted a sharp reduction in man-hours and/or the use of lower-cost manpower.

We conclude, therefore, that there is considerable reason to doubt whether productivity is decreasing in the services. This conclusion may be consistent with the findings of the authors of INFORUM, that an increasing part of the working force is shifting to those sectors that have a lower rate of growth of productivity. It is necessary to examine this claim in more detail.

The authors of INFORUM divide their analysis into two parts -- an analysis of changes in coefficients (discussed below), and a change in productivity. Each of these is analyzed at a detailed level, but each analysis involves little more than extrapolation of past trends. However, if there has been a slow-down in productivity because of a gradual increase in use of services, then this should be apparent at the aggregate level as well. An analyst using aggregate data on productivity in the U. S. should arrive at the same projections as an analyst making many detailed projections. We have already seen that this did not occur -- that INFORUM uses a lower projection of GNP than do other analysts.

It is not possible, with the information at hand, to explain definitively why the difference arises. A possible explanation is that improvements in productivity shift from one part of the economy to another. The United States began with most of its working force in agriculture and other extractive trades. The first improvements in productivity had to be in these industries. There were followed by the improvements associated with large plants that produce basic materials such as steel and chemicals. These improvements included such developments as the substitution of petroleum for wood. In the next stage, emphasis shifted to fabrication and mass production, which culminated in the 1960's with substantial increases in the speed of metalworking. Some service sectors (e.g., airlines, telephones) also experienced major improvement in productivity at that time.

It is not unreasonable to expect that attention will now turn to the service trades. In most of them, suggestions have been made as to how productivity might be dramatically improved. Some possible examples:

Medical services: Greater use of handbooks that permit the patient to take over his own care, once diagnosed; and greater use of nurses and aides to deal with some of the tasks of the General Practitioner.

Education: Greater use of tapes and movies.

Retail and wholesale trade: Coaxial Systems in homes that permit ordering from an automated system.

Banks: Paying of bills by card that communicates directly with the computer memory.

These examples demonstrate that an improvement in productivity in the services could be beginning, even though it is not apparent in the blurred data available to economists.

Since the available information does not justify any specific projection of productivity, it would seem most appropriate to use the projection that is the most "official". For this reason the present study uses the most recent estimate of productivity and GNP given by the Bureau of Labor Statistics since this is the official long-run projection of the U.S. Government.

Critique of the Macroeconomic Projections

The constructors of macroeconomic models have solved a number of important problems that will affect the future of economic analysis.

(a) The pragmatic problem has been solved as to how to support the continued construction and testing of models of the economy. By establishing organizations that are financed by subscription, they ensure the continuity of the analysis and the continued testing and improvement of models to forecast macroeconomic variables.

(b) The models permit the incorporation of detail. The available models have, to date, provided projections of the level of output of industries. Other kinds of detail would be possible as user support is developed.

(c) The projections by different analysts are quite similar (see Figure 5.4). The differences are numeric and can well be interpreted as the difference in observation that arises from different observers of the same phenomena.

Nonetheless, the foregoing reveals many difficulties that macroeconomic projections have not solved as yet.

(a) There is insufficient relationship between the problems faced by projection models and the process of data collection. The lack of relationships stems largely from differences in organizational locale. In the U.S., the offices that collect data, such as trade associations and the Census Bureau, do almost no construction of models. The builders of models have limited resources and are seldom able to revise or replace published data to any extensive degree. The difficulty has been seen in measurement of the productivity of services, but this is only one example of a large number of areas in which accuracy of models calls for changes in the customs of data collection.

(b) While macroeconomic models are tested empirically, no additional techniques have been developed, comparable to the techniques in this paper, that would permit the user to criticize and correct details of the time series or the formulation of the model. This limitation is discussed above in connection with projections of PCE (pp. 137-138).

(c) While macroeconomic models are able to incorporate detail, the existing models are exceptionally aggregate (except for industrial detail). The models incorporate the level of detail that is discussed in newspaper columns -- e.g., total Federal expenditure, interest rates, etc. Political controversy, which considers the implications of default by New York City, cannot obtain answers from models that use average interest rates or an average tax level for all state and local governments.

Of course, additional detail cannot be afforded unless someone will pay for it, and they in turn must find the additional detail useful. This raises many new problems such as what types of detail (in addition to industrial detail) can be supported by some users, what is the relationship of detailed analyses to the macroeconomic models that have been developed.

(d) A major difficulty that arises in making economic projections is the inherent incompleteness of economic models. There are many phenomena that affect the economy but are not predictable solely by economic variables. An example is the desire to work on the part of adult women. The proportion of women seeking work has been increasing, and present models extrapolate past trends. However, more women have sought jobs than has been projected, so the unemployment rate has risen. (The "unemployment rate" is defined as the proportion of people seeking work who are not employed.) Presumably the proportion of women seeking work is affected by many attitudes -- e.g., desire for independence, desire to have and care for children, need to "amount to something," response to increased affluence -- that will be more accurately projected by sociologists than by economists.

Economic models have attempted to be holistic, to deal with all parts of a national economy. They have only dealt with one aspect, however, the "economic" aspect. Other aspects also affect the same phenomena. That is, economic actions may also obey patterns that are recognizable in other theories (e.g., increased obesity as a cause of death) but not in economic theories.

The following are some of the relationships which must be projected in order to make macroeconomic projections:

the death rate of children and people of working age,
levels of immigration and emigration from the U.S.,
proportion of people seeking work,
the unemployment rate that is acceptable politically,
productivity in various industries.

The theory as to why these will vary are given in many different disciplines including medicine, political science, sociology, and engineering. From the point of view of economic theory, these relationships must be treated as contingent, and economic models can be used to define the structure of economic dependence. That is, economic models are able to compute the impact upon all aspects of the economy of changes in the variables that are projected by other disciplines. Economic models can also identify which changes would have the most significant effect upon the economy. The models can help to identify, then, the projections of other disciplines that are of most significance for economic projections.

It will be seen in the next section that the contingent nature of technology has a special role to play in projections of economic variables.

CHANGES IN INPUT-OUTPUT COEFFICIENTS OVER TIME

It has been mentioned in Chapter 2 and 3 that the coefficients of the input-output model are not assumed to be invariant over time. This section will consider several methods by which projections of coefficients can be made. It then provides projections of solid waste for 1985.

Leontief, in his first edition,[10] showed that input-output coefficients are not constant over time. In his second edition,[11] he showed that changes in coefficients appeared to involve trends. That is, input-output models were less accurate 20 years apart than they were 10 years apart. It therefore became accepted practice to measure the amount of change in coefficients and to extrapolate past changes into the future. The extrapolations used in INFORUM are of two different kinds: (a) individual coefficients, and (b) across-the-row changes. The larger coefficients in some of the larger industries are extrapolated individually. For each of the other industries, a correction is made that applies to the entire industry, and every term in the row is changed by the same proportion. The method is to calculate for each year the total use of the material that would have occurred if the input-output coefficients were constant, and to compare this total with the actual use of the material. This difference, year by year, gives a trend (which may be zero, of course) which is then extrapolated. No variable other than calendar time is used. In INFORUM the extrapolation is permitted to slow down or speed up, but not reverse itself. Table 5.3 gives across-the-row changes that were used in INFORUM.

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[10] Leontief, Wassily W., The Structure of the American Economy, 1919-1929, Cambridge, Mass., Howard University Press, 1941.

[11] Leontief, Wassily W., The Structure of the American Economy, 1919-1939, New York, Oxford University Press, 1951.

TABLE 5.3

ACROSS THE ROW CHANGES IN COEFFICIENTS 1971 - 1985 FOR INDUSTRIES SIGNIFICANT IN THIS STUDY

INDUSTRY	CHANGE 1985/71	EXCEPTIONS*
COTTON [4]	None	
NARROW FABRICS, YARNS & THREAD MILLS [35]	.82	
LUMBER PRODUCTS [41]	.79	
VENEER & PLYWOOD [42]	1.14	
MILLWORK & WOOD PRODUCTS [43]	1.36	
PAPER & PAPERBOARD MILLS [48]	.89	
PAPER PRODUCTS NEC [49]	1.05	11
WALL & BUILDING PAPER [50]	.83	
PAPERBOARD CONTAINERS [51]	1.05	
PLASTIC MATERIALS & RESINS [62]	1.07	
SYNTHETIC RUBBER [63]	1.17	
CELLULOSIC FIBERS [64]	.81	
NON-CELLULOSIC FIBERS [65]	1.51	
TIRES & INNER TUBES [72]	1.17	
RUBBER PRODUCTS [73]	.96	
MISC PLASTIC PRODUCTS [74]	2.18	
LEATHER TANNING + INDUSTRIAL LEATHER PRODUCTS [75]	.73	
GLASS [78]	1.07	
POTTERY [80]	None	
STEEL [83]	.86	34
COPPER [84]	.88	
LEAD [85]	.77	2
ZINC [86]	.88	
ALUMINUM [87]	1.07	1
PRIMARY NON-FERROUS METALS, NEC [88]	.92	
METAL CANS [92]	.97	
METAL BARRELS, DRUMS & PAILS [93]	.84	
METAL STAMPINGS [97]	.94	

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*Number of individual terms not covered by across-the-row changes, e.g., of the 142 coefficients representing sales of paper products [49], 11 are adjusted using data appropriate only to them, and all of the remaining 131 coefficients are adjusted by the same ratio, 1.05. When this column is empty, then every coefficient in a row is adjusted by the same term.

Extrapolation has its risks, of course. For example, based upon past trends, INFORUM projects that the use of coal will decline and the use of natural gas will increase. Since reserves of natural gas are declining[12] and reserves of coal are quite extensive, most energy specialists expect these past trends to reverse themselves.

The use of the same change for every coefficient in a row can result in errors in the analysis of solid waste. For example, it is assumed that the quantity of plastic per phonograph record will increase at the same rate as to plastics in a motor vehicle. Yet in the one case, plastics are being substituted for metals. Again, it is assumed that aluminum in packaging is growing at the average rate for aluminum. In fact, Containers and Packaging shows the increase of aluminum in packaging is faster than is indicated by such an assumption. The method of adjustment by changing all coefficients along a row leaves much to be desired.

Projections of Solid Waste: Results of the Study

The projections take account of the following:

(a) The path products, given in Appendix C

(b) Changes in consumer expenditure, 1971 to 1985

(c) Changes in input coefficients, 1971 to 1985

(d) The adjustments for price, waste, and truncation made in this study, given in Appendix B-3.

The results in Table 5.4 represent the purchase of inputs in 1985 which will eventually become solid waste. However, some materials are used many years before they are discarded. Table 5.5 gives estimates of the average length of use of various end uses. By extrapolation between 1971 and 1985, it is possible to estimate the composition of discarded waste in 1985. The result is given in Table 5.6. A comparison of the 1971 inputs with the results in Table 5.4 and 5.6 is given in Table 5.7.

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[12] Federal Power Commission, A Realistic View of U.S. Natural Gas Supply, December, 1974.

TABLE 5.4

INPUTS PURCHASED IN 1985 FOR PRODUCTS GOING TO CONSUMER HOUSEHOLDS

INDUSTRY	LUMBER & WOOD PRODUCTS [41]	PAPER & PAPERBOARD MILLS [48]	WALL & BUILDING PAPER [50]	PLASTIC MATERIALS & RESINS [62]	SYNTHETIC RUBBER [63]	GLASS [78]	STEEL [83]	COPPER [84]	LEAD [85]	ZINC [86]	ALUMINUM [87]	OTHER PRIMARY NON FERROUS METALS [88]
TOTAL	11,544	46,918	397	5,176	2,757	19,212	33,575	84	314	15	1,130	433
CONTAINERS & PACKAGING		23,240	164	1,980		16,608	5,694				344	
Food & Kindred Products [23 - 34]						15,626						
Drugs [66]						982						
HOUSEHOLD DURABLES	1,314			614	69	745	5,462	4			165	10
Floor Coverings [36]												
Furniture [45,46]	1,288						518					
Household Appliances [123]	10			556	49	178	2,996	4			150	
Radio & TV Receiving [125]	16			58	6	567	586				15	10
Farm Machinery (lawn mowers)[103]					14		975					
Service Industry Machinery [116]							387					
TRANSPORTATION	6,140		174	305	120	958	19,219	49	29	15	581	18
Motor Vehicles [133]				275	107	958	17,306	45	29		343	18
Trailer Coaches [140]	6,140		174	30	4		1,084	4		15	188	
Cycles [139]					9		829				50	
BUILDING												
Owner-Occupied Dwellings [167]	810		59	84	12	230	288	11				

UNIT: Thousand Metric Tons

TABLE 5.4 (Continued)

INPUTS PURCHASED IN 1985 FOR PRODUCTS GOING TO CONSUMER HOUSEHOLDS

INDUSTRY	LUMBER & WOOD PRODUCTS [41]	PAPER & PAPERBOARD MILLS [48]	WALL & BUILDING PAPER [50]	PLASTIC MATERIALS & RESINS [62]	SYNTHETIC RUBBER [63]	GLASS [70]	STEEL [83]	COPPER [84]	LEAD [85]	ZINC [86]	ALUMINUM [87]	OTHER PRIMARY NON FERROUS METALS [88]
MISCELLANEOUS	3,280	23,678		2,193	2,556	671	2,912	20	285		40	405
Products	1,812	3,995		417	266							
Textiles & Apparel [35,37,38,39,40]												
Tires [72]					2,123	14	75					
Footwear & Leather Products [76,77]	278	119		457	98		15					
Newspapers [52]		15,585										
Periodicals [53]		2,613										
Books [54]		1,107										
Phonograph Records [126]				269								
Electrical Lighting [124]						87	317					
Batteries [129]				14	8				278			
Optical Equip. [143]						22						
Watches, Clocks [146]				48			14					7
Jewelry & Silverware [147]				74	2		92	20				398
Toys, Sporting Goods & Musical Instruments [148]	1,190	259		914	59	390	408		7		40	
Other						158	1,991					

UNIT: Thousand Metric Tons

TABLE 5.5

YEARS BETWEEN PURCHASE AND DISCARD BY END PRODUCT

INDUSTRY	FIRST OWNER	OTHER OWNERS	DELAY IN DISPOSAL	TOTAL TIME
TOTAL				
CONTAINERS & PACKAGING	0			0
Food & Kindred Products [23 - 34]	0			0
Drugs [66]	0			0
HOUSEHOLD DURABLES	0			0
Floor Coverings [36]				
Furniture [45,46]	10	5		15
Household Appliances [123]	10		5[1]	15
Radio & TV Receiving [125]	10		5[1]	15
Farm Machinery (lawn mowers)[103]	5			5
Service Industry Machinery [116]	10	5		15
TRANSPORTATION				
Motor Vehicles [133]	4	6	5[2]	15
Trailer Coaches [140]	10	5		15
Cycles [139]	4	6	5[2]	15
BUILDING				
Owner-Occupied Dwellings [167]				

[1] Retained by owner for subordinate years; e.g., in basement

[2] Retained by junk yards for cannibalization of parts

INDUSTRY	FIRST OWNER	OTHER OWNERS	DELAY IN DISPOSAL	TOTAL TIME
MISCELLANEOUS				
Products	5			5[3]
Textiles & Apparel [35,37,38,39,40]	4	1	1	6
Tires [72]	2			2
Footwear & Leather Products [76,77]	2			2
Newspapers [52]	0			0
Periodicals [53]	0			0
Books [54]	15			15
Phonograph Records [126]	5			5
Electrical Lighting [124]	10			10
Batteries [129]	3			3
Optical Equip. [143]	5			5
Watches, Clocks [146]	5			5
Jewelry & Silverware [147]	5	5		10
Toys, Sporting Goods & Musical Instruments [148]	5			5
Other	15			15

[3] This applies to all products except paper which is discarded in the same year.

TABLE 5.6

COMPOSITION OF DISCARDED HOUSEHOLD SOLID WASTE IN 1985 BY PRODUCT

INDUSTRY	LUMBER & WOOD PRODUCTS [41]	PAPER & PAPERBOARD MILLS [48]	WALL & BUILDING PAPER [50]	PLASTIC MATERIALS & RESINS [62]	SYNTHETIC RUBBER [63]	GLASS [78]	STEEL [83]	COPPER [84]	LEAD [85]	ZINC [86]	ALUMINUM [87]	OTHER PRIMARY NON FERROUS METALS [88]
TOTAL	8,073	46,413	294	3,903	2,445	17,858	26,148	48	287	11	751	278
CONTAINERS & PACKAGING		23,240	164	1,980		16,608	5,694				344	
Food & Kindred Products [23 - 34]												
Drugs [66]												
HOUSEHOLD DURABLES	874			136	44	286	3,656	2			70	4
Floor Coverings [36]												
Furniture [45,46]	859						787					
Household Appliances [123]	6			125	20	76	1,968	2			64	
Radio & TV Receiving [125]	9			11	3	210	295				6	4
Farm Machinery (lawn mowers)[103]					11		387					
Service Industry Machinery [116]							219					
TRANSPORTATION	4,386		130	76	60	487	15,194	30	20	11	305	11
Motor Vehicles [133]				68	52	487	13,750	27	20		164	11
Trailer Coaches [140]	4,386		130	8	2		782	3		11	109	
Cycles [139]					6		662				32	
BUILDING												
Owner-Occupied Dwellings [167]												

UNIT: Thousand Metric Tons

TABLE 5.6 (Continued)
COMPOSITION OF DISCARDED HOUSEHOLD SOLID WASTE IN 1985 BY PRODUCT

INDUSTRY	LUMBER & WOOD PRODUCTS [41]	PAPER & PAPERBOARD MILLS [48]	WALL & BUILDING PAPER [50]	PLASTIC MATERIALS & RESINS [62]	SYNTHETIC RUBBER [63]	GLASS [78]	STEEL [83]	COPPER [84]	LEAD [85]	ZINC [86]	ALUMINUM [87]	OTHER PRIMARY NON FERROUS METALS [88]
MISCELLANEOUS	2,813	23,173		1,711	2,341	477	1,604	16	267		32	263
Products	1,572	3,995		338	230							
Textiles & Apparel [35,37,38,39,40]												
Tires [72]					1,964	13	71					
Footwear & Leather Products [76,77]	265	113		407	92		14					
Newspapers [52]		15,585										
Periodicals [53]		2,613										
Books [54]		653										
Phonograph Records [126]				210								
Electrical Lighting [124]						58	240					
Batteries [129]				11	7				261			
Optical Equip. [143]						18						
Watches, Clocks [146]				34			11					6
Jewelry & Silverware [147]				32	2		61	16				257
Toys, Sporting Goods & Musical Instruments [148]	976	214		679	46	309	359		6		32	
Other						79	848					

UNIT: Thousand Metric Tons

TABLE 5.7

COMPARISON TABLE OF INPUTS AND WASTE FOR 1971-1985

INDUSTRY AND ALMON SECTOR	1971 INPUTS	1985 INPUTS	1985 WASTE
LUMBER AND WOOD PRODUCTS [41]	7,693	11,544	8,073
PAPER AND PAPERBOARD MILLS [48]	29,064	46,918	46,413
WALL AND BUILDING PAPER [50]	291	397	294
PLASTIC MATERIALS [62]	1,709	5,176	3,903
SYNTHETIC RUBBER [63]	1,330	2,757	2,445
GLASS [78]	9,405	19,212	17,858
STEEL [83]	25,690	33,575	26,148
COPPER [84]	49	84	48*
LEAD [85]	220	314	287
ZINC [86]	11	15	11
ALUMINUM [87]	578	1,130	751
OTHER PRIMARY NON-FERROUS METALS [88]	217	433	278
FIBERS [4], [64], [65]	3,809		

UNIT: Thousand Metric Tons

*Buildings are omitted from waste which permits this figure to decline.

Appendix D gives projections for each path and describes the method by which Table 5.4 was derived.

Comparing the inputs for 1971 with inputs for 1985, the results are not surprising. The largest growth is for plastic materials with large proportionate growth in the use of rubber, glass, aluminum, and other metals. The difference between inputs and waste depends largely upon the type of end use and the length of time in use. Metals and lumber are sold to uses that involve long delays. It is important to emphasize that the 1971 estimates (taken from Table 4.3) represents inputs and do not represent the composition of waste as disposed of. The input-output model does not provide a basis for estimating waste as disposed of. Table 4.3 apparently overstates the composition of steel and lumber in waste for 1971.

Contingent Changes in Coefficients

It is not necessary to extrapolate changes in coefficients. Various authors have been able to link changes in coefficients to explicit changes in design. For example, Vernon L. Smith found that "improvements in truck engines and fuels have caused the consumption of fuel per ton-mile in intercity trucking to decline roughly 1-2/3% per year during the period 1940 - 1952."[13]

IR&T[14] has analyzed the substitution between plastic and glass containers in a study that illustrates the steps that are required. It was necessary to define the attributes of containers (e.g., permeability, transparency, etc.) and the importance of these attributes for various uses. For example, many drugs lose potency rapidly in plastic containers because plastic is permeable and glass is not. For those uses in which both materials are effective, a model was developed that takes account of scale economies of production. Since plastic is challenging glass and has an expanding market, economics of scale will favor plastic and will permit it to reduce its costs -- and eventually to dominate markets that it is presently entering.

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[13] Smith, Vernon L., "Engineering Data and Statistical Techniques in the Analysis of Production and Technological Change: Fuel Requirements in the Trucking Industry," *Econometrica*, Vol. 25 (1957), pp. 281-301.

[14] Ayres, Robert, James Saxton & Martin Stern, *Materials-Process-Product Model*, International Research & Technology Corporation, July, 1974.

This study illustrates some requisites of a study of changes in technology. The analysis must define the physical context in which change is occurring. There may be a change in efficiency (e.g., improved design that permits less use of metal per object, or decreasing grade of ore) or a change in properties (e.g., the development of alloys with improved properties). Quite frequently the change involves a substitution of a material for one or more other materials. Then the following requirements must be met:

(a) Technological feasibility must be established for specific uses of the materials,
(b) The ratio of substitution must be determined, and
(c) The delay of substitution must be estimated.

Delays can be associated with at least three factors:

(1) Consumer acceptance of the new materials,
(2) Resistance of workers to use of the new material in production,
(3) Costs of production, including scale economies and learning curves.

Studies of contingent substitution are costly and are beyond the scope of the present study.

Scientific Status of the Input-Output Model

There are several reasons why it is difficult to define a set of empirical tests that would determine whether the assumptions of the input-output model are valid:

(a) it is accepted that input-output coefficients will change over time,
(b) there is no accepted rule as to how the coefficients are expected to change over time.

Together, these conditions mean that if an input-output model does not predict accurately, then it may be that the coefficients have changed in ways not accounted for. An important philosopher of science[15] has shown that it is always possible to deflect criticism away from a theory and onto the various "auxiliary hypotheses" that are associated with the theory. Any theory can be saved to the extent that analysts are willing to adjust other statements than the theory. The point that needs to be emphasized is that the theoretical systems used by economists are less definite, permitting a greater amount of reinterpretation, than do most physical theories. Econometric theories permit the user to re-estimate his equations or even replace an equation by additional equations after each test. The input-output model is even more extreme in its permissiveness, and because it includes a large number of coefficients, there are more ways in which it can be updated.

To the extent that the testability of a theory is the criterion as to its scientific status, then the input-output model is less "scientific" than most theories in physical science as well as of econometrics. However, a system such as input-output can also be viewed as a mathematical system (rather than as a scientific theory) which is to be appraised according to its usefulness. We have seen a number of ways that the input-output model is useful in making empirical projections of an economy.

(a) It provides an accounting framework for identifying gaps in data and reconciling data.

(b) It provides a mathematics that is readily manipulated to define an inverse matrix (indirect impacts). The mathematical operations can be dissected by computing path products. Empirically, a direct enumeration of path products is found to account for a large proportion of the indirect effects and hence to permit the user to define the significance of changes in individual coefficients.

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[15] Lakatos, Imre, "Falsification and the Methodology of Scientific Research Programmes," in Criticism and the Growth of Knowledge, edited by I. Lakatos and A. Musgrave, Cambridge, England, at the University Press, 1970, pp. 91-195, especially pp. 132 ff.

(c) The input-output model can be sufficiently disaggregated, and path products are sufficiently comparable to physical flows, that the computations of the model can be interpreted and corrected so as to conform to our knowledge of technical relationships that are used in production.

Viewed as a mathematical framework, the input-output model provides a translation between economic problems (e.g., employment, output levels of industries) and technological information. Economic projections can be based upon a large number of statements concerning technological dependence. The accuracy of the projections depends upon the ability of the analyst to acquire and fit into the model an accurate body of statements concerning present and future technological dependence. The ultimate contact with reality, for technological statements, is, of course, the experiments of scientists and engineers and the production capabilities of workmen. The problem for the model builder is to reflect this knowledge at a level of detail adequate to project its impacts upon other economic variables.

The projections of the model can still be tested, of course. What is being tested is the ability of the input-output model to provide a useful mathematical framework for organizing a social process which consists of a group of people acquiring, organizing, and translating data and technological information so as to make conditional predictions. Testing is also a social process which includes determining the conditions that have occurred and determining what happened that can be compared with the predictions.

Scientific investigation and testing is always a social process, but social analysis may depend more than physical analysis does upon the skill of the analyst and the extent to which the analysis must be updated. In any case, it is costly to develop, appraise, and update economic models of the kind considered in this chapter.

Technological information contains many statements that define changes in coefficients that are expected in the future. For example, motor vehicles are being designed to be lighter so as to conserve gasoline. This involves replacing steel by plastics and aluminum or using smaller quantities of high-strength steel which contains alloys. IR&T has undertaken several studies of future automobiles[16, 17] that enumerate components and determine the material expected to be used in each component. These studies are done at greater detail than can readily be incorporated into an input-output table, but the summarized results of these studies have been incorporated into input-output tables so as to determine the implication upon the remainder of the economy. Thus, the input-output model can be used to bridge between considerable technological detail and the impact of detailed changes upon other parts of the economy.

It is generally the case that technological statements of the future define several contingencies rather than providing a unique projection. The contingencies that are defined are not alternatives in the sense used in mathematical programming but are possibilities which are yet to be resolved by engineering, design, and management decisions. It is possible for economic analysis to compute the implication of each contingency and hence to determine the differential impact upon the economy of the technical decisions yet to be made.

An economic model that takes account of technological options can explore the implications of technical decisions yet to be made. The policy maker can use such a model in order to provide guidance as to which operations have desirable properties from the point of view of the Government.

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[16] Ayres, Robert U. and Stedman B. Noble, Economic Impact of Mass Production of Alternative Low Emissions Automotive Power Systems, prepared by IR&T for DOT, March 6, 1973.

[17] Roig, Robert W., et al, Impacts of Material Substitution in Automobile Manufacture on Resource Recovery, prepared by IR&T for EPA, Draft Final, October 16, 1975.

THE SIGNIFICANCE OF SEAS

The Strategic Environmental Assessment System (SEAS)[18] is an extensive model, developed by EPA, that utilizes demographic, economic, and technological projections in order to forecast environmental conditions to the year 1985.* SEAS has a close relationship to the present study in a number of ways:

(a) SEAS also uses INFORUM and uses the GNP of the Interagency Growth Model;

(b) one part of the SEAS model has been patterned after the present study.[19]

SEAS has several properties that are of concern to this study: it is "modular" and it uses a "phased development". It will be useful to examine what is meant by each of these and the significance that each has for the present study.

In referring to SEAS as "modular", we mean that it consists of a set of modules (models) which are tied together. Each module can be computed separately, although most modules require results that are obtained from other modules. Each module produces a detailed report as well as inputs to other modules. Furthermore, each module has a "scenario capability"--i.e., it is possible to change certain critical assumptions in the module and to utilize SEAS to determine the consequences within the module as well as upon other modules.

Figure 5.5 shows the location of the module for Solid Waste. This module receives results from INFORUM regarding levels of production. The material balance given in equation 2.9 is used in the analysis: all

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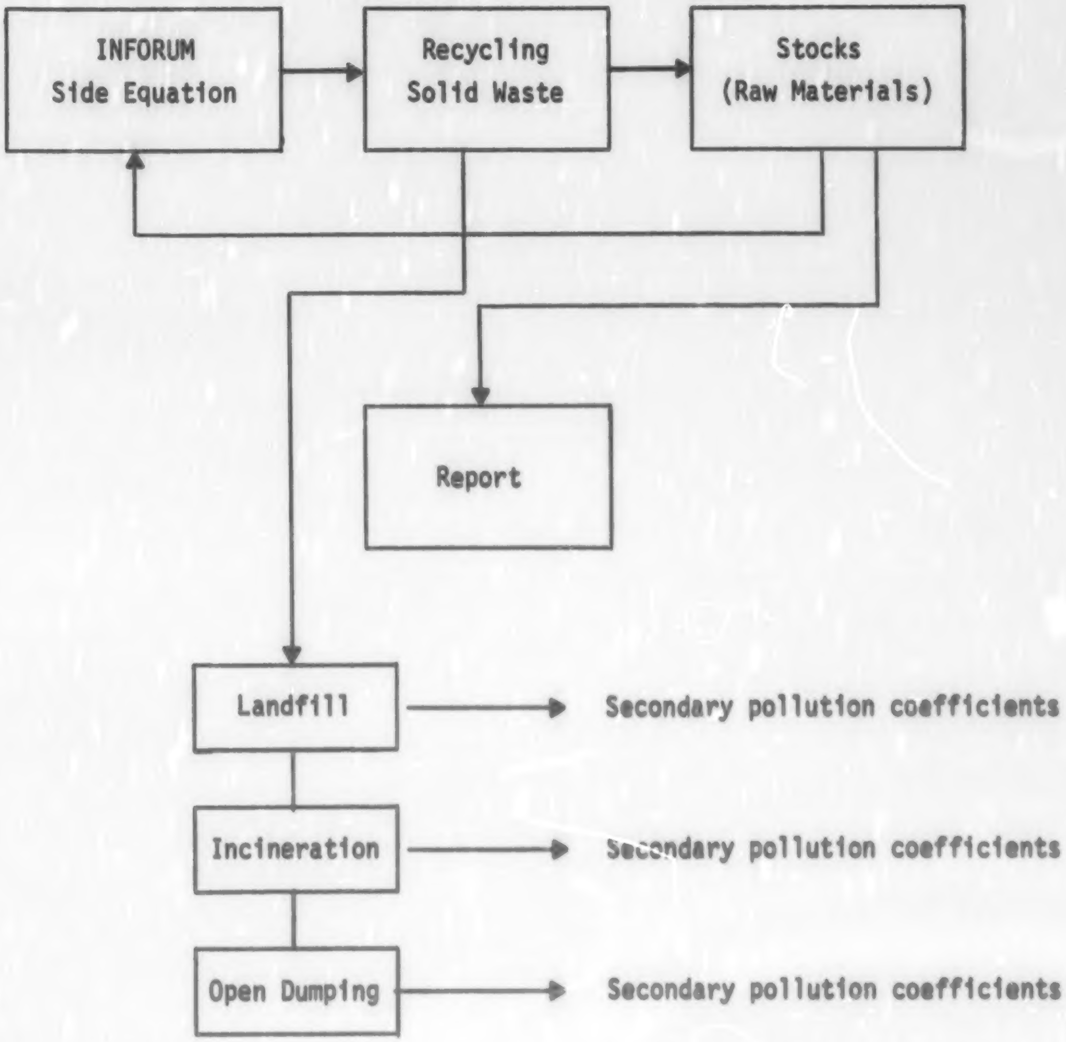
*Phase IV of SEAS, now under development, will project to the year 1990.

[18] U.S. Environmental Protection Agency, Strategic Environmental Assessment System, Prototype Documentation, Phase III, 1975.

[19] Kramer, Marc and Stedman B. Noble, "Solid Waste/Recycling", Design Paper, IRT-SEAS-DP, December 3, 1974.

Figure 5.5.

RECYCLING - STOCKS MODULE IN SEAS


INFORUM Side Equation
Recycling Solid Waste
Stocks (Raw Materials)
Report
Landfill
Secondary pollution coefficients
Incineration
Secondary pollution coefficients
Open Dumping
Secondary pollution coefficients

production becomes either industrial scrap or solid waste. The module then makes an assumption regarding the rates of recycling of discarded objects by type. The level of recycling reduces the demand for raw materials and affects their rate of depletion. The depletion of raw materials results in requirements for investment in mines and mills. The changes in production levels and investment of mines and mills are then used to adjust the production levels and investment demand in INFORUM.

The fact that SEAS has a "phased development" means that it is continually being improved. At any point in time, a version of SEAS is available for policy studies; but this version of SEAS is also being reviewed and improved. At specific intervals, the improved version of SEAS becomes the revised official version of SEAS.

This has a major consequence for the possibility of taking account of technological information in studies of solid waste. To the extent that SEAS is used to determine the implications of technological options, then the implications for solid waste will automatically be determined. For example, a study cited above* analyzes the possible materials composition of future automobiles and then uses SEAS to determine the metal by type that becomes available for recycling. This is compared with the requirements for scrap metal by the industry that recovers scrap metal.

The property of having a phased development has a major bearing upon the relevance of criticism. If a criticism is made that calls for revision, then this revision can be incorporated into the next improvement of SEAS. The continued availability of SEAS means that a revision can affect analyses in the future. Since SEAS is the central, large model of EPA, such revisions may affect many other studies.

Having a model such as SEAS gives an agency a stable framework for its accumulation of knowledge. Such a model provides a role that is comparable, in certain senses, to the role of theories in the physical sciences. If a theory is classified as "true", then any improvement which can be made by the establishment of a theory which is "more true" has considerable significance. In the domain of social and technological analysis, the "ultimately true" model can never be constructed because of the range of available knowledge and the limited time for analysis. An "official" model that is capable of revision can provide a definition of the degree of approximation that is presently being used. Any analysis can begin with the existing module in SEAS, can improve it, and can provide the improved version as a part of a revised integrated model which has both a "normal" mode and a scenario capability to prove the implications of hypothetical situations.

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*See Roig, et al, Reference 17.

The role of SEAS in EPA gives heightened importance to the methods of the present study. This study spells out the assumptions that are being used in a part of SEAS and thereby invites criticism of this part of SEAS. To the extent that all parts of SEAS are so handled, and to the extent that they are revised or survive criticism, then the results of SEAS can be accepted as the most accurate results that are currently possible.

The Administrative Relevance of SEAS

We have already seen that the construction, testing, and updating of an economic model is an expensive social process. SEAS is being developed and improved by a government agency so the needs of the agency should govern its development. SEAS can afford to include and update detail only to the extent that it contributes to the requirements of EPA. Three different classes of uses can be identified, each one making use of certain aspects of SEAS.

(1) Fast Uses: To assist in appraising changes in policy or new contingencies. The user might be a policymaker or it might be an analyst who wishes to explore the wider implications of a study that is underway. These uses call for a model that is available for computation. The assumptions of the model should be identifiable and should be readily altered so as to determine the implications of alternative possibilities.

For such uses, the model should attempt to include overrides of any variable that might frequently be treated contingently.

(2) Preparation: To provide background information for other studies. Often a study takes a year or more and requires considerable background information such as standard projections of GNP, inventories of plants by industry by location. SEAS can provide base-line projections of standard economic variables, and it also contains a large number of inventories of information. These, as well as the assumptions of its modules, could be provided to anyone starting to analyze certain areas in depth. This would simplify the beginning stages of a study and would provide information that could be criticized, corrected, and extended.

Obviously, to the extent that SEAS is more complete, then special studies will be unnecessary or easier (and therefore cheaper) to carry out. This poses two coordination tasks:

(a) how to determine the amount of detail to include and update in SEAS as opposed to leaving for special studies;

(b) how to coordinate the special studies so as to obtain from them the largest amount of general-purpose information.

Once a major study is done, then relevant parts of it can be used to update or extend portions of SEAS. In return, SEAS can be used to compute any wider implications that have not been analyzed during the study. (Presumably it is the SEAS staff rather than the staff making the special study that will be familiar with how to so revise SEAS.)

(3) Regional Uses: To have its regional data critiqued and to provide projections of regional difficulties. There is a natural symbiosis between SEAS and regional expertise. The specialists familiar with a region are apt to have the most accurate to most updated information so they can provide a criticism of the data in SEAS. On the other hand, SEAS can provide projections which take account of national economic growth and future technology and can therefore provide considerable guidance on evaluating the problems that will arise in a region. It would

seem to be desirable to disseminate the results of SEAS to regional experts who can both critique its details and learn from its scope.

Prospectus. Because SEAS contains a module which is based upon the analysis of this study, future estimates of solid waste can continue to be derived, in part, from this work. The method and approach of this study will provide continued computations and projections of solid waste, but based upon updated information and additional contingencies.

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16. Ayres, Robert U. and Stedman B. Noble, *Economic Impact of Mass Production of Alternative Low Emissions Automotive Power Systems*, prepared by IR&T for DOT, March 6, 1973.

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CHAPTER 6

RECOMMENDATIONS

Since the study of solid waste reported in this paper has been incorporated (in slightly altered form) into SEAS, recommendations can be divided into two parts: the improvement of solid waste modeling and the improvement of SEAS.

Recommendations for Modeling of Solid Waste

(1) A solid waste module, to be associated with SEAS,* should be maintained in updated form. This module should be extended to cover all kinds of solid waste -- household, commercial, industrial overhead, industrial scrap.

(2) The data gaps cited in Table 4.22 should be filled.

(3) The solid waste module should be extended to take account of the activities of waste collection and recycling as well as the associated manpower requirements and emissions.

Recommendations for the Use of SEAS in EPA

(4) Continue to maintain SEAS, keeping it up to date and keeping it operational computationally.

(5) Maintain and extend connections between SEAS and models developed by other agencies so as to permit additional scenario capability.

(6) To the extent that this is not done by the Department of Commerce on INFORUM, the input-output portion of SEAS should continue

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*INFORUM and the Interagency Growth Model (References 1 and 6 of Chapter 5) are maintained, so in the absence of SEAS, the module could be associated with these.

to be improved. Major candidates are to translate many rows into physical units and to revise prorating assumptions when they lead to significant errors.

(7) Develop coordination between SEAS and major studies done by EPA so that the studies will provide answers needed for the improved accuracy of SEAS. Coordinate the exchange of information with local units that can correct and update details of SEAS while utilizing the computations and projections provided by SEAS.